PORTLAND CEMENT,

AND

PORTLAND CEMENT CONCRETE.

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PORTLAND CEMENT: ITS MANUFACTURE, USE, AND TESTING.

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WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPERS.

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I.

(Paper No. 2512.)

"Portland Cement: its Manufacture, Use, and Testing."

By HENRY KELWAY BAMBER, F.I.C.

PORTLAND cement is generally made from a mixture of clay and chalk. The clays are obtained chiefly from the estuaries of the Medway and other rivers, and vary somewhat in different districts, some containing small quantities of carbonates of lime and magnesia. The average composition of a good clay is as follows:—

Silica	54·84
Alumina and oxide of iron	25·08
Lime	0·90
Magnesia	0·80
Carbonic acid	0·83
Sulphuric acid	1·20
Organic matter and moisture	16·35
	100·00

Any clay having a similar composition will do; but these river clays possess the advantages of being easily broken up and mixed with the chalk and water in the washing mills. As in this process the proportion of the ingredients must be kept as uniform as possible, it is necessary to make constant chemical tests, otherwise the resulting cements may differ greatly in quality. The chalk used also varies to a certain extent; but ordinary soft chalks of the following average composition are the best:—

Silica	1·15
Alumina and oxide of iron	0·78
Lime	54·00
Magnesia	0·25
Carbonic acid	42·50
Organic matter, &c.	1·32
	100·00

In the older works, the mixture of clay, chalk, and water obtained in the washing mills is run into backs, and allowed to settle. The water is then drawn off, and the solidified mixture carried to drying plates, to remove the greater part of the remaining moisture. These drying plates are heated by coal or coke, and in some cases are so arranged that the waste heat of coking ovens is used for the purpose. In more recently erected works, the slurry is only mixed with sufficient water to enable it to run along the troughs that conduct it to the horizontal flues in direct communication with the interior of the kilns. All the heat that passes from the kilns during the burning of the cement is thus carried over the slurry, which is dried rapidly and cheaply. These flues also being part of the kilns themselves, less labour is required in packing the kilns with the dried slurry and coal or coke. In either case, when the slurry has been sufficiently dried, it is carefully packed into the kilns with the proper mixture of coal or coke. The quality of the resulting cement depends to a great extent on the careful performance of this part of the process, for if the clay and chalk mixture be added in too large lumps, the outside only will be properly clinkered, while the interior will remain an imperfectly-burned powder; whereas thorough clinkering is absolutely necessary in order to obtain good cement.

The first effect of the heat on the mixture in the kilns is to drive off water and carbonic acid, thereby converting the chalk into quicklime, which decomposes the clay, combining chemically with both the silica and alumina, forming calcium silicate and calcium aluminate, of which properly-burned cement chiefly consists.

Clinkering is a state of semifusion, and it is requisite that this should take place in the kilns, so that when they are emptied there shall be only good clinkers without dust. It is on this process that the production of strong cement depends, for it is at the time of this semifusion that the chief chemical action takes place. In the clay, which is mainly a silicate of alumina, the silica and alumina are in intimate chemical combination, the silica acting the part of the acid, and the alumina that of the base. Alumina, however, has also the power under certain circumstances of taking the place of an acid, and this occurs during the semifusion in the kiln; the lime decomposes the clay, and combines both with the silica and alumina, forming calcium silicate and calcium aluminate, which, when finely ground, constitute good cement. When mixed with water, the cement combines chemically

with a certain quantity, and crystallizes into a solid block impervious to water. In the case of concrete, where sharp quartz sand is used, some of the lime gradually combines chemically with it, forming an additional quantity of silicate of lime, and this still further improves the strength of concrete. During the process of absorption of water and crystallization, the whole should be kept as much at rest as possible, for excess of water, especially in motion, would separate the finer particles and weaken the concrete, and form an incrustation of white chalk, &c.

In order to know whether a cement obtained from any manufacturer is good, a complete chemical analysis is requisite in the first place to show if it has the right composition. This will, however, only give the proportions in which the ingredients exist, which may be exactly the same in a well-clinkered cement as in one that has only been burned enough to drive off the water and carbonic acid, without causing any further chemical action between the several ingredients. The usual test of proper burning is the weight of a striked bushel of the cement, which is required to be not less than 112 lbs. to 115 lbs. This is a very uncertain test, as many little points during the filling of the mixture may make several pounds difference in the weight. A much more reliable test is the specific gravity, which should accompany the analysis. A properly clinkered and ground cement, when new, will have a specific gravity of 3·1 to 3·15. If it is as low as 2·9, or less, it shows that the cement has not been properly burned, or has become deteriorated by exposure to the air.[1] Thus, the chemical analysis gives the actual composition of the cement,

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[1] In taking the specific gravity of cement, the Author, being anxious to do without turpentine, which expands rapidly with every increase of temperature, had bottles made, holding about 1,000 grains of water. The bottle is filled accurately with water at 60° Fahrenheit from a cistern, wiped dry and clean, and weighed. About two-thirds of the water is then poured out, and 100 grains of cement, accurately weighed, are then poured in through a dry glass funnel, the finger is tightly pressed on the mouth, and the whole well shaken for three or four minutes to prevent setting. The bottle is then again filled with water from the same cistern, where the temperature will not have changed, the stopper is again inserted, the bottle wiped dry and clean, and again weighed. If no water had been displaced by the cement, the whole should weigh 100 grains more than before; but it will be found that, with a good new cement, it will weigh about 32 grains less than this, which will be the weight of the quantity of water equal in bulk to the cement. If, then, the 100 grains be divided by this 32, it will give the specific gravity of the cement, viz., 3·125. The bottle can then be easily washed out, for the shaking of the cement with excess of water has prevented its setting; and the difference in temperature at the two weighings is inappreciable.

and the specific gravity gives the density, which cannot be brought up to 3·1 unless the ingredients have been thoroughly and properly clinkered.

Cement is often stored for some weeks and turned over to lessen its tensile strength, with the mistaken notion of making it safer to use. The high tensile strength now realized is obtained by using a larger quantity of lime than formerly, and the object of exposure to the air is to weaken the excess of lime. Experiments made by the Author with newly-ground cement, having a specific gravity of 3·1, with 61·5 per cent. of lime, and giving a tensile strength of 400 lbs. to 500 lbs. per square inch at seven days, show that such a cement, if properly mixed with a full quantity of water, is perfectly safe and reliable.

The next thing to be considered is the fineness to which it should be ground, which varies in different specifications. It is important that the whole of the cement should pass through a sieve of about 2,500 meshes to the square inch, and not less than 90 per cent. of it should pass through a sieve of about 5,625 meshes to the square inch. The reason why it is necessary that it should all be finely ground is that although 90 per cent. might pass through a sieve of the above fineness, yet if the residue was coarse, all the cement would not absorb sufficient water at the same time; the fine particles would set quickly, and the coarser ones slowly, and probably not until after the principal part had hardened. The larger particles absorbing water after this would cause internal expansion and the disruption of the cement, in the same way as small lumps of lime become disintegrated. The specific gravity would also be low if it was mixed with the so-called iron slag cement, which is merely a mixture of finely-powdered iron slag and slaked lime, not a Portland cement. The Author was the first to make small quantities of cement from iron slag, which were made into blocks, and tested as regards strength by Mr. John Grant in 1873. The large quantity of sulphur in iron slag is a great objection. Some slags contain little or no alumina; and only those from clay ironstone are at all applicable. The next test is the breaking strain, at seven, fourteen, or twenty-one days, of blocks of (*a*) neat cement, and (*b*) a mixture of one part of cement and three parts of fine sand. The breaking strain required varies greatly in different cement specifications; some stipulate for a breaking strain for neat cement of not less than 400 lbs. per square inch at seven days, and of 580 lbs. per square inch at twenty-eight days. With the view of detecting blowing, it is also required that slabs or cakes of the material, after

immersion in water for twenty-four hours, shall show no signs of cracks or softness. It would be advisable to make some of these test slabs in the proportion of one part of cement to three of sand, for with neat cement, the outside may set thoroughly and protect the portions in the middle by being impervious to water, and if the water cannot get access to any coarse particles that are inside there would be no blowing, although they may be there all the time. Unfortunately the blocks made up to test the breaking strains very often vary considerably, with the same cement, under different manipulators; and complaints are frequently made to manufacturers of low breaking strains, when the fault lies with the way in which the blocks have been made. Every engineer, using large quantities of cement, should have each cargo subjected to all the above tests for his own credit and safety; for in many cases it happens, if the engineer has not these tests to rely on, that an inferior material is praised by dishonest foremen who use it, when a first-class cement is complained of as being bad by the same men—a deception which can only be detected by thorough testing.

The setting of Portland cement is very similar to that of plaster of Paris, which will set quite hard if new, when mixed with the proper quantity of water, but, when six months old, will not do so, even if it has been kept in an airtight case. The atoms of fresh cement greedily take up water, and become solid; but a gradual molecular change renders the cement less capable of taking up and combining with this quantity of water, until at last it does not set at all, although the chemical composition may be exactly the same. The specific gravity, however, of the cement is continually becoming less.

When Portland cement was less finely ground than it is at present, it was well to keep it some time before use, because then most of the larger particles were reduced to powder; but with the fineness given above, it is not only useless, but detrimental, to keep it for more than a month. Though briquettes made with new, and with old cements do not confirm this, it must be remembered that the cement in briquettes is mixed with as little water as possible, and forced into the moulds, a very different state to that in which it is mixed in concrete in actual work. As a rule, in making briquettes with new cement, a larger quantity of water is required than with old cement. In making these briquettes, a definite quantity of water, 20 to 25 per cent. of the weight of the cement, should in all cases be used; and the cement that sets best, and bears the greatest strain, at the usual periods, under these circumstances, will be the best.

As to the proportions of the ingredients, theory indicates that 50 per cent. of lime would be quite sufficient; and the Author is still of opinion that if cement could be prepared with this proportion of lime, and properly clinkered, having a specific gravity when new of 3·1, it would be quite sufficient. He has had kilns of cement prepared in this proportion on two or three occasions, which (although the full amount of coke was used) took half as long again to burn the same quantity as when the mixture contained 61 to 62 per cent. of lime, and was not then well clinkered, and rapidly fell to powder when the kilns were opened. After several experiments, he came to the conclusion that when the lower quantity of lime is present, as soon as the water and carbonic acid are driven off, the mixture falls to powder and lessens the draught, instead of at once beginning to agglutinate and clinker, as it does when the larger proportion of lime is used; and if the same quantity of fuel takes thirty-six hours to burn instead of twenty-four, the temperature obtained is much lower, and not sufficiently high to properly clinker the cement, which is thus of inferior quality. Therefore, with the present form of kilns, engineers obtain a far better cement having 61 to 62 per cent. of lime, than with much smaller proportions of lime. This high proportion of lime is safe, even when new, if the concrete is properly mixed, and with the full quantity of water it can absorb.

Two years ago the Author made experiments with blocks of concrete in the proportion of 4 parts of shingle, 2 of sand, and 1 of cement. The cement was new, with a specific gravity of 3·1, and was composed as follows:—

Silica	23·32
Alumina and oxide of iron	12·13
Lime	61·56
Magnesia	1·07
Sulphuric acid	1·28
Carbonic acid	0·30
Organic matter and loss	0·34
	100·00

Three sets of blocks were made in duplicate, and in each pair there was exactly the same proportion of every ingredient, with some water. The first pair were mixed with the full quantity of water that the cement would take up, which proved to be 10 lbs. for each block. The second were mixed with only 7½ lbs. of water, or three-fourths of the full quantity. The third pair were mixed with 5 lbs. of water, or half the full quantity. After standing for a

fortnight, one of each of these pairs was placed on a sea wall; and they were covered and uncovered by each tide. They stood there twelve months; and at the end of that time were brought on land, and carefully broken through the middle. The results were as follows:—No. 1, with the full quantity of water (10 lbs.), was very hard and perfectly sound, and dry quite through to the surface. No. 2, with three-quarters of the full quantity of water ($7\frac{1}{2}$ lbs.), was dry in the middle; but on every side the water had penetrated about 3 inches, and had much weakened the block. No. 3, with half the full quantity of water (5 lbs.), was wet quite through, and was very easily broken up, the water having been able to percolate continually through the block, and having dissolved much of the lime. The fellow pair of each of these was placed in fresh water, and remained the same time, with exactly similar results as to penetration of water and strength of blocks; but in these cases another result could be observed. In the case of No. 1, with the full quantity of water (10 lbs.), the water in which it stood remained clear. In the case of No. 2, with three-quarters of the full quantity of water ($7\frac{1}{2}$ lbs.), the water in which it stood became milky and turbid from the formation of carbonate of lime. In the case of No. 3, with half the full quantity of water (5 lbs.), the water became quite white; and at the end of twelve months, the whole block was covered with crystals of carbonate of lime a quarter to half an inch in thickness. The lime had been gradually dissolved, and crystallized on the surface in the form of carbonate of lime. Similar blocks subsequently exposed in the sea wall for nearly three years gave the same results.

In making other blocks recently, 5,184 cubic inches of shingle, 2,592 cubic inches of sharp sand, and 1,296 cubic inches of cement, measured separately, were mixed with 30 lbs. of water, and put into a box 18 inches cube, completely filling it without any residue. Exactly the same quantities of shingle, sand, and cement were then mixed with 15 lbs. of water, with the result that a box of the same dimensions could only hold seven-eighths of the mixture. This shows that when mixed with insufficient water, the concrete occupies one-eighth more space than when mixed with the full quantity of water it can take up. Therefore there were air spaces in the latter block, equal to one-eighth of its bulk more than in the first block, which, when placed under water, would allow water to percolate into and through it. Concrete also made with cement a month old, and mixed with a full quantity of water, expands in setting and fills its allotted space, in the same manner as ice and type-metal; but with old cement this is not the case.

These experiments show that the quantity of water used in mixing the concrete is very important; and, in fact, on this depends, to a great extent, the difference between getting good and bad concrete from the same cement. In the case of the fellow block on the sea wall, no crystals were formed, because the lime was washed away as soon as it was dissolved. The Author's explanation of the difference of the behaviour of blocks that merely varied from each other in the quantity of water used, all the other ingredients being the same, and in same quantities, is the following:—The setting of Portland cement is due to the combination of the cement with water, to form a definite chemical combination. This, with a sufficient quantity of water, makes a hard, impervious compound, which is not liable to deterioration. Whereas, if an insufficient quantity of water is used, it sets, but in an incomplete manner. In this condition it is not impervious to water, and is very liable to become weakened by frost, and by the action of water in motion; and this is the cause of the milky fluids and sediments formed so frequently in concrete works. The lime gradually dissolves forming, in the case of fresh water, carbonate of lime; and in the case of sea-water, the solution of lime decomposes the salts of magnesia in the sea-water, and the deposits contain carbonate of lime and magnesia in varying proportions. Again, when the quantity of water used in mixing concrete is not sufficient to ensure proper crystallization, the finer portion of the cement may take its full quantity of water, leaving the remainder in a condition to take up more water on the first opportunity—which, if it happens after the concrete has once set, causes internal expansion and disruption of the mass, or blowing on a large scale.

Frequently, with the object of making concrete extra strong, it is mixed comparatively dry; and then astonishment is felt when the work fails. A full quantity of water is an absolute necessity; but, on the other hand, the cement must not be drowned in water, which would separate the particles, washing away some, and preventing setting altogether.

In a cement made from dolomite, the above result would be likely to happen, owing to the presence of a large quantity of magnesia, even when plenty of water had been used in mixing; for lime absorbs water rapidly, becoming slaked or hydrated quickly, whereas magnesia only absorbs water slowly. The cement, therefore, containing it may set, owing to the lime present; but if after this, water obtains access to the interior, the magnesia gradually becomes hydrated, expands, and causes disruption of the concrete.

In conclusion, the properties of good reliable cement are:

(1) It should be finely ground. (2) A chemical analysis should give the composition mentioned above. (3) It should have a specific gravity of not less than 3·1 at the end of a month after being ground. (4) It should give the usual tensile strengths with briquettes at 7, 14, and 28 days, made with neat cement, mixed with a specified quantity of water, and also with briquettes made of 3 parts of fine quartz sand and 1 of cement.

A cement which conforms to these requirements, if mixed with the full quantity of water it can take up, about 40 lbs., or 4 gallons to each cubic foot of cement, will give results that will be satisfactory and permanent.

II.

(*Paper No. 2385.*)

"The Inspection of Portland Cement for Public Works."

By Alfred Edward Carey, M. Inst. C.E.

In this Paper it is proposed to deal with the measures which appear desirable for the inspection of Portland cement for Public Works, in relation to its manufacture and use.

The Papers on cement by the late Mr. John Grant,[1] and the discussions to which they gave rise, led to the general use of a system of tensile tests; and the subsequent development of the manufacture, and of the present system of testing cement, are described in several Papers in the Minutes of the Institution.

Manufacture.

Some supervision of the manufacture is almost essential in order to judge of the quality of Portland cement; and in the specification of any contract in which it forms a vital constituent, power should be reserved to the engineer, or his agent, to visit the works of the maker at discretion. This is especially desirable in cases in which it is only possible to institute short-term tests. The points of greatest importance are: uniformity of raw materials; completeness of the mechanical blending; the proportion of carbonate of lime; thoroughness of wet grinding; the burning; the flouring; the aeration; and the packing of the finished cement.

Uniformity of Raw Materials.—The variation in the amount of coarse sand present in the clay (*i.e.*, of grains of free silica too large to enter into combination at the clinkering temperature) is of importance, as it is practically a passive adulterant. Its proportion may be tested by an elutriator, or Shone's apparatus.

The Author finds that gault clay contains an average of about 3 per cent. of sand, and the Gillingham mud about 7·9 per cent. The percentage of uncombined silica should not exceed 1 per cent.; but many cements now in the market contain 2 per cent. or more.

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[1] Minutes of Proceedings Inst. C.E., vol. xxv. p. 66, and vol. xxxii. p. 266.

The analyses of two samples of gault clay, from Kent and Sussex respectively, are as follows :—

Constituents.	Kent.	Sussex.
Water of combination and organic matter.	4·09	3·43
Oxide of iron	4·03	4·33
Alumina	12·69	13·13
Carbonate of lime	21·97	
Lime	..	10·58
Carbonic acid, alkalies, &c.	..	11·73
Magnesia and alkalies	0·88	
Insoluble siliceous matter	56·34	56·80
	100·00	100·00

The essential constituents of cement are lime, silica, and alumina (generally in combination with iron), the other bodies, when not present in excess, acting negatively.[1] The substances to which the hydraulic properties are due are the silica and alumina (with iron); and the highest standard of quality is probably attained, when 6 parts of lime, 2 of silica, and 1 of alumina with iron, are present in combination, the ratio being $\frac{\text{Lime}}{\text{Hydraulic Factors}} = 2$. Oxide of iron in the clay, in any considerable proportion, affects the colour of the cement; and gypsum and iron pyrites reduce the rapidity of its setting, besides causing it to attain its maximum tensile strength more rapidly. Gypsum, if present in any quantity affects disastrously the permanence of the strength of cement, and for this reason great caution is necessary in using gault clay. An excessive proportion of clay increases the rapidity of the setting, while an excess of lime retards it. Slow-setting qualities render a cement, therefore, unsafe for use, unless due to age or thorough clinkering.

White and grey chalk, as well as the many varieties of limestone, are used for the manufacture of Portland cement. Grey chalk is more easily washed than the white; but, in using it, greater vigilance is necessary with the calcimeter, owing to its varying chemical composition. Another source of lime has been proposed, namely, the vat waste, in connection with the Chance sulphur recovery process, in which the precipitate is in the finest possible state of

[1] For analyses of cement and raw materials see Appendix I.

mechanical subdivision. Cement made from magnesian limestones, or from those in which the salts of magnesia are present in any considerable proportion, are often highly dangerous for reasons stated hereafter.

Completeness of the Mechanical Blending of the Raw Material.—The Author considers that the best shape for the washmill tank is octagonal. The mill should be driven at a high velocity (say 22 revolutions per minute), as the materials are thus combined with a minimum of water; 25 per cent. of water being the best result obtained to the Author's knowledge. The system of settling backs has generally given place to the Goreham process. The former, apart from the length of time, and the space it necessitates, allows the materials to settle in strata of different density. It is claimed by some makers that this is an advantage; as, when sandy clay is used, it enables the coarse sand to be dug out and removed from the slurry. In laying out new works, however, the Goreham system is now generally adopted. Most makers advocate weighing the raw materials into the washmill; but this, owing to the varying proportions of moisture they contain, is little real check; and careful calcimeter, or other chemical tests, taken periodically, are essential. The washmill used is of a type similar to those employed in brickworks, but for so thick a material as cement slurry, the power it absorbs is excessive. At the Reliance Portland Cement Works, Rochester, the Author has recently introduced with success an edge-runner mill for this purpose.

Factories are now in operation for utilizing a deposit of chalk marl, near Cambridge, for the manufacture of Portland cement. The conditions are unusually favourable, the marl being remarkably regular in chemical composition, and blended physically to perfection; so that Portland cement clinker, of a high class, can be produced by burning the material, to a large extent, in a raw state, as dug.

Proportion of Carbonate of Lime.—The greatest care is necessary in keeping the composition of the wash constant; and calcimeter tests should be made at intervals of a few hours. It is desirable that engineers, in specifying the quality of Portland cement, should require evidence of the proportion of carbonate of lime contained in the slurry. Probably 76 per cent. will be found to give the best results in most cases; but the amount of coarse sand, or intractable silica in the clay, has to be considered in this connection. There has been a reaction of late against cements which develope a high tensile strength quickly. Probably, con-

sidering the analyses of the raw materials commonly used in manufacture, and the ordinary systems of burning, a percentage of less than 72 per cent. would, in the majority of cases, result in a permanently weak cement. No hard and fast rule is possible, for to produce analogous results, the proportions of lime and alumina should vary inversely; and, subject to the above reservations, the clinker should result in a chemical compound of definite constitution within narrow limits.

Thoroughness of Wet Grinding.—The wet grinding is one of the most critical operations in the manufacture of cement, and neglect at this stage is fatal to good results. All slurry, as it flows from the wet stones, should be ground so fine, that after the moisture has been expelled it may leave a residue not exceeding 8 per cent. on a 22,500 mesh; but it is difficult, when white chalk is used, and there is much flint, to obtain so good a result. The usual practice is for the wet miller, at intervals, to wash a handful of the wet slurry through a sieve of 1,600 or 2,500 meshes per square inch, testing it constantly for its creaminess, or absence of grit, by touch. This system, however, gives imperfect results. In clinker produced from badly ground slurry, minute particles of caustic lime are visible; and after dry grinding, these became hydrated, and slowly absorb carbonic acid from the air, the absorption with well-burnt cement, spread in thin layers, being about 1 per cent. in the first four days. Even if sufficiently hydrated before use not to blow in the work, the caustic lime is inert and soluble, and in sea-water, it sets up a precipitation of magnesia.

Burning.—Chemically, the first effect in burning is to expel the carbonic acid from the carbonate of lime, producing oxide of calcium, or caustic lime. This change takes place at 440° Centigrade (824° Fahrenheit); and the silica and lime gradually unite to form silicate of lime, until a temperature of 700° Centigrade (1,292° Fahrenheit) is reached, when the alumina comes into action, uniting with the silicate of lime to form a body of complex constitution. The temperature rises to about 1,600° Centigrade (2,912° Fahrenheit), but this degree of heat should be kept up for a short time only, otherwise a glassy, and comparatively inert substance is formed, instead of a body in a condition of potential chemical activity. Although chemically identical in composition, the clinker produced with prolonged heat has a comparatively permanent crystalline structure. The iron which, in contact with lime, fuses at a lower temperature than the other bodies in combination, forms a film upon the clinker of a bluish black colour; and the greenish bloom on the surface of well-burnt clinker is attributed

by Dr. Michaëlis[1] to the trace of manganese present in the clay. This probably exists in combination with ferric oxide; and the colour described is a good index of well-burnt clinker. The combinations of lime, silica, and alumina, being of a whitish colour, and covered with coloured substances, underburnt clinker will have a greenish grey tint, overburnt clinker a dull bluish black, unless an excess of sulphur is present in the clay or the fuel, when it will be mottled with red or yellow. About 13 per cent. of alumina is probably the maximum desirable to ensure the best results, as with more than this, in producing the more complex alumina compounds, the simpler silica compounds are overburnt, and rendered inert when hydrated in gauging.

In modern cement works, closed kilns, of which a large variety of types are in use, are generally adopted; and in these, the waste heat from the burning is utilized for drying the slip upon adjoining floors. The Author proposes to use the term "metamorphism" in classifying the changes produced by the partial fusion which takes place in the burning of cement. This action probably bears considerable analogy to the processes of transformation, which occur in the production of igneous rock masses. That lime acts as a flux is shown by variations in the proportions of the raw materials affecting the quantity of fuel necessary to bring about the desired degree of metamorphosis. Under similar conditions, the free lime in the clinker is inversely proportionate to the degree of heat attained. Spontaneous pulverization may often be observed in cement clinker, a large mass rapidly flying to pieces, and becoming merely a heap of powder, intense heat being simultaneously disengaged. This result has been shown by Mr. H. Le Chatelier,[2] to be due solely to the presence of the bicalcic silicate, $SiO_2.2CaO$. The powder so produced is devoid of cementitious properties.

The systems of burning generally in use appear eminently unscientific, as large masses of hard clinker are produced, the crushing and grinding of which are costly processes, involving great wear and tear. Moreover, if the core of these masses is properly burnt, the outside must be overburnt, and *vice versa*. Specifications vary widely in their requirements as to the burning. One specification compels the clinker to be broken into pieces which will pass through a 4-inch ring, and requires that all the under-burnt and over-burnt portions shall be carefully picked out by daylight.

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[1] Das Wesen und der Erhärtungs-Process des Portland-Cementes.

[2] Recherches expérimentales sur la Constitution des Mortiers Hydrauliques, p. 53.

The picking out of the "yellows" and "pinks," or under-burnt clinker, is more important than that of the "glassy," or over-burnt, the former causing disintegration, while the latter is merely a passive adulterant. The processes of Mr. W. Joy (Messrs. Peters Bros.), and Mr. F. Ransome, Assoc. Inst. C.E., have for their object the production of clinker in a state of finer subdivision, and more uniformly burnt, than that hitherto obtained. In the latest development of the Ransome system, the dried slip is reduced to a fine powder, in a mortar mill or otherwise. It is then fed into a hopper communicating with an inclined iron cylinder lined with firebricks, several courses of which are deeper than the rest of the lining, thus forming longitudinal ledges. The cylinder is made to revolve, and the powdered slip, in its revolution, is thus alternately lifted and dropped until it leaves the lower end. At this end, a flue is led into the cylinder, and is in connection with a gas generator. The combustion of the gas in the cylinder roasts the fine particles of powder, which are delivered in the form of cement clinker in a spongy condition, and ready for the dry grinding. This system was tried, but subsequently abandoned, at the works of Messrs. Gibbs and Co., Grays, and also at the Arlesey Works, Bedfordshire. Mr. W. Stokes has introduced an improvement upon this process, which is being put into operation at the Arlesey Company's works. In Joy's process, a wet mixture of slip and fuel is fed through an eye at the side of a domed kiln, the upper surface of the contents of which is covered with slip, thrown by hand to any point in the crust at which flames may burst through. Dried slip without fuel is fed into the kiln in increasing proportions as the burning off progresses. The high quality of the cement made by this process, the Author considers to be due to the conversion of carbon dioxide into carbonic oxide, no vapour escaping from the kiln, and a blue lambent flame playing over the surface of the burning mass. The flame of carbonic oxide, burning in air, is estimated to have a temperature of about 2000° Centigrade (3,632° Fahrenheit).[1] An intense heat, of short duration only, is thus applied over the crust of the burning mass; whereas long-continued heat tends to deteriorate the quality of cement clinker. In this case, the clinker comes away in honey-combed masses which have been burnt in detail. A more friable and uniformly burnt clinker is thus produced, which requires less power in grinding than ordinary clinker, the wear of the kilns by Joy's process being also much reduced. A somewhat

[1] C. L. Bloxam's Chemistry, 1886, p. 89.

similar result is aimed at in the Dietsch kiln, which is in use on the Tyne, and near Cambridge.

One of the most valuable data in connection with the burning, is the specific gravity of the cement, as was pointed out by Sir Frederick Bramwell, Past Pres. Inst. C.E., in 1865.[1] The apparatus described by him, is similar to that now known as Dr. Schumann's,[2] in which the specific gravity is found from the displacement of turpentine in a graduated glass tube, by the insertion of a given weight of cement. Care should be taken that the moisture and carbonic acid are expelled from the cement before using the instrument, as it has been demonstrated that, with age and exposure, the specific gravity is materially decreased. A result much lower than 3·1, after drying for fifteen minutes in a desiccator, may generally be taken as an indication that the clinker is underburnt. The specific gravity of a given cement is the same whether it is finely or coarsely ground. A minimum of 3·0 was fixed by the Munich Congress of 1884; and the standard of 3·1 has been objected to as excessive. A low specific gravity combined with a high tensile strength at seven days, are conditions pointing to an unreliable cement, which will rapidly deteriorate. The test of the weight per bushel should be abandoned, and the specific gravity substituted, the former being so inexact as to be practically valueless.

Flouring.—There is no condition in cement-making where the requirements of the users have been more progressive than that of fineness of grinding; and the specification of a residue of 10 per cent. on a 50 $\times$ 50 mesh is fast becoming obsolete as a standard test. The residue, even from a mesh of 32,257 divisions per square inch, possesses practically no cementitious value when gauged with sand; and in cement, it is the "flour," or impalpable powder, which is the really effective part, the "nibs," or coarse residue, forming an adulterant equivalent to the admixture of a similar proportion of sand. With finely ground cements there is, moreover, less risk from the expansion of the caustic lime from hydration.

The increase in value of a cement due to fineness of grinding is shown more clearly by sand tests than by neat tests, each minute particle requiring to be painted over by a thin coating of cement

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[1] Minutes of Proceedings Inst. C.E., vol. xxv. p. 137.

[2] Minutes of Transactions of the Verein Deutscher Cement-Fabrikanten, Feb. 1883, p. 47. [See also "Elements of Agricultural Chemistry," by Sir Humphry Davy, p. 176.—SEC. INST. C.E.]

in gauging; and the more finely ground it is, the greater the surface which is thus covered. The Author is of opinion that in specifications, it would be far better to allow a large percentage of residue on an exceedingly fine mesh than a small residue on a coarser mesh. The practice of sieving on works does not necessarily conduce to an improvement in quality, as the miller, trusting to the sieves to reject any coarse particles, may set his stones so as to produce a cement of coarser average than would be possible if he was grinding without sieves. In the one case, the grind would have to be maintained at the maximum, in the other case, at the mean of the required degree of fineness. The following results demonstrate the value of fine grinding. The tests were made with one part of cement, of specific gravity 3·125, and three of standard sand gauged with 10 per cent. of fresh water. The temperature of the air and of the cement was 46° Fahrenheit, and the results were obtained at twenty-eight days, being the average of 6 briquettes in each case.

Cement.	Tensile Strain per Square Inch Section. Lbs.
As ground, *i.e.*, 9 per cent. on 50 × 50 mesh . . .	220
With residue on 50 × 50 mesh removed.	304
With residue on 75 × 75 mesh removed.	311
With residue on 32,257 mesh removed	360

Dr. Michaëlis[1] has proved the inertness of the residue upon a sieve of 5,000 meshes per square centimetre (32,257 per square inch) by sand tests made, (1) with a given volume of cement as ground, (2) with the smaller volume of cement due to sifting out the residue on this mesh. The strength of the tests was not materially reduced by the loss of the coarser particles, which were therefore of no cementitious value. This has been further proved by the Author, by gauging into briquettes the residue left upon this mesh, when a feebly cohering mass results.

Cement, as it comes away from ordinary millstones, has a temperature of 150° to 160° Fahrenheit; and in grinding cement of a specific gravity of about 3·1, and of a fineness of about 8 per cent. on a 2,500 mesh, an ordinary pair of 4½ feet millstones, driven at 140 revolutions per minute, produce 25 to 32 cwts. per hour, and absorb 35 to 40 HP. Edge-runner mills have been tried at various times, with doubtful results as to quality, the absence of the shearing action of millstones appearing to produce particles

[1] Zur Werthstellung der Zemente. (Deutsche Bauzeitung No. 101, 1876.)

which, not being subdivided along the lines of cleavage, fail to bond in gauging. A comparative trial made by the Author, of a new edge-runner mill, with the same degree of fineness, gave results superior in tensile strength to that ground in the ordinary way. The net power absorbed per ton per hour, in grinding, was 14·96 HP.; and the cement left the mill at a temperature of 75° to 77° Fahrenheit.

Aeration.—With the imperfect systems of burning and grinding generally in use, it is essential that cement should be well aerated or "purged" before use, in order to air-slake any caustic lime it may contain, the high temperature at which it is delivered from millstones also necessitating exposure in order to cool it. The more finely ground a cement is, the more rapidly air-slaking is effected; and probably in a few years the improvements now being introduced in the manufacture will render aeration unnecessary, and cement will be produced in a fit state for immediate use. The quantity of cement stored should be not less than ten weeks' production; and the distributing worms or belts should be arranged so as to deliver the cement, as it comes away from the dry mill, to any part of the store. By this means the expensive and unpleasant operation of turning and spreading it by hand, may be to a large extent avoided. In accepting tenders for cement, the capacity of the store at the factory in question is a matter worthy of careful consideration; as, in times of pressure, makers will often be tempted to load up imperfectly aerated cement. A proper arrangement of bins is also desirable, as it assists an inspector in making sure that the cement which he has sampled is really consigned. A little observation will enable him to estimate, from the rate at which the compartments allotted to his order are being emptied, whether any attempt is being made to pass off other material than that which he has sampled.

Packing.—Attempts have been made from time to time to improve the packing of cement for transport or shipment; but sacks and barrels still hold the field. The size of the former, for English use, is equal to 10 or 11 to the ton; for French export, 50 kilogrammes (about 1 cwt.) each. Water-proof sacks have been used for export purposes, but have never come into common use. The cost of 400-lb. machine-made casks per ton of cement varies, with the number of hoops and bars, from 7*s.* to 7*s.* 6*d.* With hand-made casks, the cost is from 9*s.* to 10*s.* per ton. In order to utilize a larger proportion of stores, both systems are often simultaneously adopted, giving an average increase of say 8*s.* 6*d.* per ton to the cost of cement for export purposes. The weight of

casks of this size is about 24 lbs. each, or 144 lbs. per ton of cement; and the rates of insurance of cement, except for total loss, are practically prohibitive.

As well-burnt cement clinker, from which the dust is removed, is little injured by exposure to any reasonable degree of damp, it might, in many cases of foreign works, be wise to erect grinding plant on the spot, and export cement clinker. An inspector should superintend the consignment up to its delivery on board, especially when it is loaded in sacks and lightered alongside the vessel.

Testing.

The types of machine for tensile testing are various, and too well known to need description; and the best shape of briquette was so carefully investigated by the late Mr. J. Grant, that this point may be considered practically determined. The early briquettes were almost universally of $1\frac{1}{2}$ inch $\times$ $1\frac{1}{2}$ inch section; but this size is rapidly being given up in favour of the 1 inch $\times$ 1 inch section. The weight of cement in a briquette of $1\frac{1}{2}$ inch $\times$ $1\frac{1}{2}$ inch section is about 2 lbs., too large a quantity to manipulate satisfactorily, especially when the material is quick-setting. The similar weight for a 1 inch $\times$ 1 inch briquette is about 5 ounces; and two briquettes, or with slow-setting cement three briquettes, are as many as should be gauged at one time. The method of clamping the moulds should be such as not to strain or jar the briquettes in getting them out. The proportion of water should be taken by weight rather than by volume. The Author considers that a handy machine is wanted to test briquettes of $\frac{1}{2}$ inch $\times$ $\frac{1}{2}$ inch section, so that an inspector may be enabled to gauge up a series of briquettes at the maker's factory more rapidly than is possible with the present machines; and this would be especially serviceable in enabling him to form a judgment in short-term tests.

The best calcimeter is the "Dietrich" apparatus, in which the carbonic acid given off, in treating a given quantity of slurry or cement with a fixed weight of hydrochloric acid, is measured by displacement of a column of mercury or distilled water. The weight of material, which has to be taken with great accuracy to the tenth of a milligram, is dependent on the temperature and state of the barometer; and this weight is taken from the Tables supplied, which have to be calculated for each apparatus. A certain quantity of carbonic acid is absorbed by the hydrochloric acid, and the correction for this is found from a second Table, and

added to the amount registered on the measuring tube of the apparatus. The moisture in the material to be tested should be expelled in a water oven at a temperature of 212° Fahrenheit, and it should be then dried in a desiccator, as these bodies are strongly hygrometric.

The conditions of a standard test in compression are as yet undefined; and some difference of opinion exists as to the desirability of instituting such tests. Dr. Michaëlis' hydraulic compression testing machines are probably unrivalled in range and accuracy. For weak bodies, such as mortar mixtures with much sand, &c., the size of the blocks used is 100 square centimetres (about 16 square inches), and for pure cement and rich mixtures, test blocks of 50 square centimetres (about 8 square inches). A pressure of 69,000 kilos (about 68 tons) may be exerted with this press, the weight of which is about 18 cwt. The cost of reliable compression testing machines is too great to admit of their general adoption; but the system of employing independent inspection of cement is likely to be more and more widely followed. It has been urged that the Institution of Civil Engineers should recommend a series of standard regulations as to the testing of cement, similar to those adopted by foreign governments and public bodies. Such a step, however, might tend to check the progressive improvement in quality, which has been so marked in spite of the want of uniformity in engineers' specifications. Cement makers are often asked to fulfil impossible conditions, and would welcome the establishment of a normal standard of quality. Had such a standard been formulated ten years ago, its effect would, in all probability, have been retrograde, tending to the production of cement of a lower average quality than has been evolved by the present system. The German rules fixed the 3 to 1 sand test at 28 days as follows:—

In 1877 at 113·8 lbs. per square inch.
In 1878 at 142·2 lbs. " " "
In 1887 at 222·5 lbs. " " "

The Prussian Ministry for Commerce, Manufacture, and Public Works has drawn up a standard specification, which is also accepted by the Berlin Society of Architects, the Society of Contractors, &c.[1] The specification adopted for the Boulogne Harbour Works[2] is approximately the standard for government

[1] A translation of this specification has been placed in the Library of the Institution.

[2] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 457.

works in France. The Austrian Association of Engineers and Architects have a code of regulations; and normal standards have been formulated in Sweden, Switzerland, and Russia. In the United States, a committee of the American Society of Civil Engineers[1] reported, in 1885, in favour of a uniform system of testing, on lines devised by them. The irregularity in the testing arrangements in the United States had previously been much complained of by English manufacturers and others, and the conditions of supply were admittedly unsatisfactory.[2] At the present time, there is no uniformity of practice amongst engineers and users of cement in the United States. If it was attempted to apply the foreign specifications quoted to English public works, they would probably remain practically a dead letter. In framing a specification for Portland cement, the essential point is to give wide discretionary powers to the engineer, or his agent, avoiding unnecessarily troublesome conditions. The Author submits a standard specification in Appendix II, which it might be necessary to supplement when the cement is to be used under exceptional circumstances. Compression tests will probably be required in the near future.

In some specifications, the seven days' test is taken at seven days after gauging; in others, at seven days after immersion. The former is preferable, as this obviates the date of breaking sometimes falling on a Sunday, in which case the briquettes are usually broken at eight, instead of seven days. Some specifications state the proportions of the raw materials to be used in manufacture; but this is an undue interference with the function of the cement maker, and is of doubtful utility. It is far more important to have evidence of the regularity of the wash, from which the degree of care and accuracy with which the manufacture is being carried on may be inferred. In specifications in which cement is to be specially quick-setting, as when required for use in a plastic state in a tideway, or in broken water, the result of tests by the Vicat needle should be required; but such vague expressions as "finely ground," "quick-setting," and "slow-setting," should be avoided in specifications. It is also undesirable to state definitely the proportion of water to be used in gauging, as this, if rigidly adhered to, may mislead; but a record of it is essential to a due knowledge of the value, for constructive purposes, of any particular sample of cement. In gauging up briquettes, the best results are

[1] Transactions of the American Society of Civil Engineers, vol. xiv. Nov. 1885.
[2] *Ibid.*, vol. vi. p. 312, Dec. 1877.

obtained with those in which a smooth, viscous, gelatinous body rises to the surface; and this quickly crystallizes into a homogeneous skin. If an excess of water is used, this face may be washed away in gauging; and, in this event, or should it be trowelled away, the breaking strains are always lower than fair maximum results. This superficial coating probably consists of the alumina silicates in solution, the nearest analogy being the hard skin produced in vitrification, or on the surface of pottery, &c. The manipulation of a cement enables an experienced gauger to form an opinion of its qualities; and any mechanical substitute for trowelling up briquettes is of dubious advantage. An ingenious contrivance with this object is the Arnold mould, in which a given weight of cement is placed dry in a mould, and, after compression in a screw press, is placed in a tray of water from which it absorbs the required proportion. One objection to this apparatus is that it is more favourable to a light, than a heavy cement, as, owing to its greater volume, the former is more compressed than the latter. A quick-setting cement is, moreover, at a disadvantage, as the immersed face becomes set before the water has penetrated equally to all parts of the briquette; and a third objection is that, as the briquettes are dealt with in a series at one operation, the weight of water absorbed by each cannot be accurately measured. Results obtained by this apparatus should not be compared with those made in the ordinary way.

Adulteration of Cement.

The adulteration of cement and the means of detecting it were investigated by Messrs. R. & W. Fresenius, on behalf of the Society of German Cement Manufacturers.[1] Probably in this country no systematic adulteration of cement is practised; but it was stated in the report above mentioned, that in Germany, bodies were frequently mixed with Portland cement so closely resembling it in chemical composition that even a quantitative analysis was not a certain guide. The behaviour of twelve samples of Portland cement from England, France, and Germany was compared with that of three kinds of hydraulic lime, three kinds of slag meal, and two kinds of milled slag, the chief adulterants expected. Messrs. R. and W. Fresenius found the principal characteristics of a pure Portland cement to be that it should have a specific gravity of 3·125 (certainly not less than 3·1), that the loss on

[1] Minutes of Proceedings Inst. C.E., vol. lxxix. p. 377.

ignition should be between 0·34 and 2·59 per cent., that 3 grammes of cement should absorb from 0 to 1·8 milligram of carbonic acid, that the alkaline substances extracted by water from 1 gramme of cement should correspond to from 8 to 12·5 cubic centimetres of decinormal acid, and that one gramme of cement, treated with normal acid, should neutralize between 18·8 and 21·67 cubic centimetres of it.

Uses.

The next few years are likely to show, not only an increase in the scope and boldness of the applications of concrete to engineering works, but also its adaptation to many minor purposes in lieu of cast-iron and timber. A trial was recently carried out by the Author, of the strength of telegraph poles of concrete and iron in combination, made under the system patented by Mr. D. Wilson, of Tilbury, Essex, with the results given below.[1]

The advantages of substituting such a material as concrete for iron and wood, in many situations, are that it does not decay or corrode; it cannot be attacked by the teredo, or the white ant; it should not be subject to expansion or contraction; its strength, especially in damp localities, should become greater with age; and in many cases it can be cheaply cast on the spot, the cement being the only material to be transported. A telegraph pole of this type collapses gradually when subjected to an extreme strain, and is thus less likely to be a dangerous obstruction on a highway or railway than wooden poles are when they snap or are uprooted. The disadvantages of concrete, as compared with wooden poles, are its greater weight, and the necessity of more care in transport to prevent injury.

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[1]

Weight Applied. Lbs.	Deflection. Inches.
240	$1\frac{1}{2}$
480	3
600	4
840	$5\frac{3}{4}$
1080	$7\frac{1}{2}$
1320	$9\frac{3}{4}$
1440	$11\frac{1}{2}$
1600	Pole slowly deflected, but did not collapse.

Weight of 31-foot pole about 840 lbs. Diameter at the butt, $7\frac{7}{8}$ inches, and at the top, 4 inches. The pole was fixed horizontally, 6 feet of the butt being wedged into a chalk bank, and a support placed $15\frac{1}{2}$ feet from the bank. The weights were applied 6 feet beyond the prop, or $3\frac{1}{2}$ feet from the end of the pole.

In order to ascertain the power of Portland cement to resist hydrostatic pressure, a set of experiments were, on the Author's suggestion, undertaken by Mr. Joseph Cash, M. Inst. C.E., at the Brighton Gasworks, the results of which are given in Appendix III.

There is great diversity in the hand-mixing of concrete, both as to the volume of water used, and the time over which the operation is spread; and these conditions directly affect the strength and permanence of the resulting work. The Author obtained the best results by using about 22 gallons of water per cubic yard of raw materials, equal to about 1 part by volume to $7\frac{1}{2}$ parts, less than this quantity not securing that glassy film upon the surface of finished work which is so desirable, and more than this washing away some portion of the soluble alumina silicates which are the active ingredients in concretion. That a sufficiency of water in gauging concrete is advantageous, will be seen from the following results; although, in gauging briquettes for tensile testing, the smallest proportion of water compatible with thorough damping is undoubtedly the best.

CRUSHING STRAINS AT TWENTY-EIGHT DAYS.

Size of Blocks.	Conditions.	Crushing Strains per square Inch.
Cubic Inches.		lbs.
$3\frac{15}{16}$ . . .	3 normal sand to 1 cement, with 20 per cent. fresh water . .	1679
	3 normal sand to 1 cement, with 10 per cent. fresh water . .	1425 (average)

The purity of the water is a matter of vital importance. On the Newhaven Harbour Works, the water used for the 100-ton foundation sack blocks was taken direct from the river;[1] and the Author found that it was essential to do the pumping on the flood tide, as on the ebb tide the river silt partially killed the cement. The percentage of earthy matter in many streams is so great [2] as to render their waters, in an unpurified state, unfit for use in concrete. To test this, six briquettes were gauged neat with 20 per cent. of distilled water, and cement of a specific gravity of 3·1, giving an average at seven days of 480 lbs. per square inch, and taking three hours to set. Six similar briquettes were gauged with a mixture of 49 parts by weight of distilled water, mixed with 1 part of Thames

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 102.

[2] Jukes' Manual of Geology, ed. by A. Geikie, pp. 423–4.

mud (equal to about $\frac{1}{100}$th mud by volume), which had been previously dried at 212° Fahrenheit, and powdered very fine. These briquettes took four hours to set, and gave an average at seven days of 411 lbs.

The effect of sulphuric acid on the strength of cement and concrete structures is demonstrated by the following results of tests, in which the same sample was used with fresh water, and with water containing sulphuric acid, each result being the average of six briquettes.

SULPHURIC ACID TESTS.

Proportions.	7 Days.	28 Days.
Neat cement, with 20 per cent. water	550	–
,, with 19 per cent. water and 1 per cent. sulphuric acid	151	272
1 cement and 1 normal sand, with 15 per cent. water . .	335	415
,, ,, with 15 per cent. of liquid, of which liquid 19 parts are water, and 1 part sulphuric acid	90	204
1 cement and 2 normal sand, with 15 per cent. water . .	-	270
,, ,, with 15 per cent. of liquid, of which liquid 19 parts are water, and 1 part sulphuric acid	50	108
1 cement and 3 normal sand, with 10 per cent. water . .	–	200
,, ,, with 10 per cent. of liquid, of which liquid 19 parts are water, and 1 per cent. sulphuric acid	Nil.	Nil.

The temperature of the water used for concrete making also deserves consideration. The experiments given in Appendix IV show the effect of freezing briquettes at various stages, and for different lengths of time, and demonstrate that in cement gauged as it is in making briquettes, frost produces no deleterious effect, the setting properties being rendered dormant thereby, and the long-term tests being practically identical with those maintained at a higher temperature.

In concrete-making on public works, in which an excess of water is generally used, the effect of frost is to disintegrate the concrete by the expansion of the water in freezing; and measures to neutralize this effect have been investigated by the Russian and American authorities. It has been found that the addition of common salt to the water enables work to be carried on during hard frosts, the proportion of salt so employed even reaching 8 per cent. A temperature of 75° to 80° Fahrenheit was found by experiment to hasten the maturing of the cement, a result to be noted in relation to work in tropical waters.

Cement briquettes gauged in sea-water set more slowly than those gauged in fresh water, owing probably to physical rather

than chemical causes; and at seven days, they show higher results by about 15 per cent. Apparently salt-water briquettes attain their maximum at from six to nine months. The results in this respect of five years testing at Newhaven Harbour[1] are corroborated by the figures, given in Appendix V, of long term tests of the cement of four English and four French makers of repute.

The molecular structure of Portland cement changes with age, its hardness and brittleness increasing, and its elasticity diminishing. There is a point, therefore, at which the cement begins to show a falling off in tensile strength, while the compression tests continue to improve. The gauging of cement with sea-water allows this result to be attained more speedily with the same cement. The setting with sea-water being slower, a more perfect crystalline structure is probably reached in a comparatively short time; so that the apparent deterioration, as evidenced by the falling off in tensile strains, is in reality rather a good sign.

There has been considerable discussion and much anxiety, during the last few years, as to the limits within which concrete may be safely employed, more especially on works in the sea. The influence of the salts of magnesia in affecting the life of a concrete structure is of special interest, having regard to the theory that, under certain conditions, the chemical transposition of lime from the cement, and magnesia from the sea-water, may produce disintegration. Two totally distinct issues have to be considered in dealing with this subject:—(1) The influence of magnesia as an ingredient in the manufacture of cement; and (2) the alleged deterioration of sound cements when subjected to the action of sea-water.

An excess of either lime or magnesia in a caustic form produces, when the cement is gauged, inconstancy of volume. Mr. Lechartier's Paper,[2] which is of great interest in relation to this question,[3] deals with a class of cements which he terms "Ciments *dits* de Portland." He describes a series of faults in concrete, which commenced to develop one year, or longer, after the construction of various works, and in which a slow and progressive chemical disintegration led eventually to its complete destruction. On analysis, the cements used in these structures were found to

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 113.

[2] Comptes Rendus de l'Académie des Sciences, vol. cii. p. 1223. The factory from which the cement in question was supplied has since been abandoned, owing to the numerous failures of the concrete, which were generally slowly developed.

[3] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 162.

contain from 21·20 per cent. to 34·72 per cent. of magnesia, and only in one case as little as 12 per cent. No marketable Portland cement would show such an analysis, and therefore the results obtained are not comparable to those of ordinary practice. Mr. Lechartier attributed the failures to the hydration of the magnesia, accompanied by an increase in its volume, long after the setting of the cement, thus causing the destruction of works, the solidity of which appeared assured.[1] Analogous effects are not uncommon when an over-limed cement is used; but such results, when due to magnesia, are less rapid in their action. The Author had once to deal with an instance of this kind. A 6-inch flooring of mass concrete gauged with fresh water, was laid in a brick building, the walls of which were 18 inches thick. It was made with under-burnt and over-limed Portland cement, gauged with fresh water. An expansion of the flooring soon commenced, which, after forcing the walls out of line, caused the floor to assume a serrated form, and finally to disintegrate. In another instance a concrete structure in a tidal estuary, made with a natural cement containing an exceptionally large proportion of free lime, became fissured and disintegrated. On analysis the Author found that 14·7 per cent. of the lime had been dissolved, and 6·23 per cent. of magnesia had been deposited.

A wide difference of opinion exists as to the alleged deterioration of concrete in sea-water under certain conditions. The quantity of magnesium in sea-water, present as chloride and sulphate, amounts to 0·6 per cent. by weight. In a porous mass of concrete, a precipitation of the salts of magnesia takes place, some of the lime of the cement being at the same time dissolved. On one side it is held that these salts of magnesia, filling the pores and interstices of the concrete, subsequently undergo a change of volume, producing disintegration. On the other hand, it is asserted that these precipitates are absolutely inert, and do not in any way affect the strength of the concrete. Dr. Michaëlis, admitting the risk of disturbance of bond due to an excess of magnesium salts in the raw materials, has recommended that cement containing more than 5 per cent. of magnesia should be avoided.[2] He subsequently stated that disintegration of Portland cement by sea-water is not due to the magnesia present, but to

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii., p. 460.

[2] Das Wesen und der Erhärtungs-Process des Portland-Cementes, April 20, 1887.

the acids with which this body is combined. Portland cement usually contains from 1 to 3 per cent., and sometimes as much as 4 or 5 per cent of magnesia. He considers it practically an adulterant, and that a correspondingly increased percentage of lime should be added to the raw materials, otherwise a low tensile strength may be anticipated. That cement with a high proportion of magnesia is of inconstant volume he thinks quite unproved; and cement tests, in which magnesia was present to the extent of 20 per cent., were under his observation for ten years, and showed no signs of flaw. He states that the weakness of many magnesian Portland cements is due to the mistake of regarding this body as actively useful, and of not adding a corresponding percentage of lime in manufacture. Tests made by him of correctly composed and properly burnt cement, containing from 18 to 20 per cent. of magnesia, show that no greater changes of volume occur in them than in normal cement with up to 3 per cent. of this substance. He does not consider it to be proved that a cement with 5 per cent. or more of magnesia, should on that account be rejected.[1]

The failure of a portion of the concrete walls of the graving dock at Aberdeen has led to considerable uneasiness with regard to concrete structures in the sea. Mr. P. J. Messent, M. Inst. C.E., reported that, in his opinion, failure was not to be traced to the use of cement of defective quality. It appears, also, that the practice of re-gauging or breaking up partially set concrete, and depositing it in this condition, which had been resorted to on other portions of the work, had not been applied to that part of the wall which gave way. From the porosity of the coating, which was composed of four parts of sand to one of cement, Mr. Messent deduced the theory of the deposition of magnesia from sea-water, its consequent expansion, and hence the disruption of the work.

Following up Mr. Messent's experiments, the Author experimented with one hundred and twenty briquettes, some made in neat cement, and others of one part of cement to one, two, three, and four of sand—an equal number of each kind. These were placed in a wooden cage, and secured at the level of low water of ordinary spring-tides at the pier-head at Newhaven Harbour forty-eight hours after gauging. They were thus exposed, not only to a constantly varying pressure due to the tidal movement, but also to the action of the waves at low-water. They were all

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[1] Wochenblatt für Baukunde, June 6, 1888.

carefully weighed and submerged before exposure, some for fourteen days, and others for twenty-eight days, three months, or six months. They were then surface dried by exposure in the air, and weighed afresh, with the results given in Appendix VI.

The average increase of weight from the time of immersion was as follows:—

Proportions.	14 Days.	28 Days.	3 Months.	6 months.
	per cent.	per cent.	per cent.	per cent.
Neat . .	4·98	2·69	1·25	12·06
1 to 1 . .	4·53	2·28	0·38	9·57
1 to 2 . .	5·06	2·25	0·51	9·29
1 to 3 . .	6·16	2·25	2·51	10·20
1 to 4 . .	4·97	2·42	3·41	12·77

The breaking strains are also given in Appendix VI; and the briquettes did not show any signs of disintegration. The Author instituted another series of experiments in order to determine the effect upon the strength of partial gauging with sea-water, or of gauging with concentrated sea-water. The following Table gives the results obtained from an average of six briquettes of 1 inch section in each case, and shows that very little difference is traceable to these conditions. The whole of the briquettes were gauged neat with 20 per cent. of water, the temperature of the air ranging from 45° to 54° Fahrenheit, and that of the cement from 49° to 54° Fahrenheit.

Table showing the Results of using Sea-Water in Gauging: in Lbs. per Square Inch.

Water.	1 Month.	2 Months.	3 Months.	6 Months.	9 Months.	12 Months.
Fresh water . . .	525	555	750	900	949	678
½ Distilled water, and ½ sea-water . .	537	542	690	650	965	592
¼ Distilled water, and ¾ sea-water. . .	542	550	620	750	950	575
Sea-water, 25 per cent. evaporated .	542½	563	590	580	890	605
Sea-water, 50 per cent. evaporated .	541	540	800	850	970	495

The briquettes were not checked or cracked in any way. The cement used in both series of trials was sound, well burnt, and ground so as to leave a residue of about 10 per cent. on a 50 × 50 mesh sieve.

The real point at issue is whether the salts of magnesia, which are admittedly deposited from the sea in porous concrete structures, are or are not inert. Magnesian limestones, when used for building purposes, are subject to weathering, especially in large cities where rain brings down sulphate of ammonia. This salt acts chemically upon the stone, producing carbonate of ammonia and sulphate of magnesia and lime, which latter are deposited as crystals in its pores, causing disintegration by their growth.[1] In situations in which ammonia may be brought into contact with concrete, it is desirable to use fresh water for gauging; and if analysis should show that an abnormal proportion of magnesia is present, the cement should, under such conditions, be rejected. Concrete, made of sound and well-burnt cement, varying from $\frac{1}{4}$ to $\frac{1}{12}$ part by volume, and gauged with sea-water, has been used for many existing structures in the sea, without visible deterioration for a long term of years. Those structures which are homogeneous, and are protected by a dense skin, are best adapted to resist the forces tending to disintegration. In the Author's opinion, no conclusive evidence has been adduced to prove that the precipitates from sea-water induce disintegration, even of fissured or porous concrete, when sound cement is used. Had such evidence been forthcoming, it would throw doubts on the durability of all such structures in the sea. In the Aberdeen experiments, it was demonstrated that free caustic lime had been washed out of the concrete, and magnesia as magnesium hydrate precipitated, with the formation of calcium chloride and sulphate. The analyses prove nothing beyond the fact that the caustic lime present was the cause of such precipitation, and that lime in this form is an unstable and soluble body. The inference that, by similar action long-continued, a dangerous portion of the lime may be dissolved out of the cement present in a concrete structure, is without proof. The precipitation of magnesian or other salts from sea-water is merely the deposition, without active chemical change and consequent change of volume, of bodies which already exist there in solution.

Summing up the facts of which undoubted evidence has been produced, it may be stated that an excess of caustic lime or caustic magnesia causes (1) disintegration by the expansion due to hydration; and (2) being soluble, when conditions permit of their washing out, they leave the concrete in a honey-combed state.

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[1] Brande and Taylors' Chemistry, p. 423.

Physical and Chemical Transformations.

If dry Portland cement is dropped through water into a mould, the cohesion is imperfect, and the mass resembles a block of friable sandstone, each particle crystallizing separately and without cohesion. In the same way Portland cement grout, containing 50 per cent. by weight of water, if poured through water into a mould, gives analogous results to the above, the cohesion of the block, if allowed to stand a few hours, being about double that when taken immediately after gauging.

Table of Compressive Strains at Twenty-eight Days.

Size of Block.	How made.	Crushing Strain.
Cubic Inches. $2\frac{13}{16}$ths . . .	Neat cement poured in dry	Lbs. per Square Inch. 1,900
" . .	Cement grout poured into mould, through water, 3 *minutes* after mixing . . .	950
" . . .	Cement grout poured into mould, through water, 3 *hours* after mixing . . .	1,900

On the other hand, a sack or barrel of cement, from the compactness of the particles forming it, after submersion, sets into a mass of intense hardness and density. Much light would probably be thrown upon the problems of hydraulicity and cohesion by microscopic examination of the physical changes induced under varying conditions. The chemical changes which take place during the setting and hardening of Portland cements, appear to hinge upon the relative proportions of lime and alumina silicates present in the raw materials. Mr. E. Fremy[1] and other chemists have shown that $SiO_2. CaO$ and $SiO_2. 2\,CaO$ do not develop characteristics comparable to those of hydraulic cements, the addition of water merely resulting in a paste which slowly dries without the phenomena of setting. Mr. H. Le Chatelier,[2] however, proved that the tricalcic silicate ($SiO_2. 3\,CaO$) possesses the quality of setting with water. Aluminates of lime were in a similar manner produced by Mr. Fremy by calcining pure lime and alumina at different temperatures. Alumina proved to be an excellent flux

[1] Comptes Rendus de l'Académie des Sciences, vol. lx. p. 993. See also Annales des Mines, vol. ix. p. 505.

[2] H. Le Chatelier's "Recherches Expérimentales sur la constitution des Mortiers Hydrauliques," p. 56.

for lime; and the aluminates of lime, represented by the following formulas, $Al_2O_3 . CaO$, $Al_2O_3 . 2\,CaO$, and $Al_2O_3 . 3\,CaO$, when reduced to powder and moistened, produced hydrates of great hardness, and possessed the property of agglomerating inert substances—$Al_2O_3 . 2\,CaO$, when combined with up to 80 per cent. of sand, binding together the mass into a block of artificial stone. One important factor in the experiments was that an intense heat was essential to develop the maximum of hydraulicity. A secondary effect is due to the production of silicates of lime, containing 30 to 40 per cent. of silica, and approximating to the formulas $SiO_3 . 2\,CaO$ and $SiO_3 . 3\,CaO$. Mr. Fremy showed that the function of these bodies in the setting of cements is to combine, under the influence of water, with the free lime in cement. Opinions are radically conflicting on the subject of the chemical grouping essential to hydraulicity, but cement makers agree that a minimum percentage of alumina of 7 or 8 per cent. is necessary in sound Portland cement. By grinding powdered slaked lime with cement clinker, higher tensile strains are attained in short-term tests. A clear knowledge of the chemical function of the lime in the setting of Portland cement would afford a clue to many obscure problems of great practical importance. The results given in Appendix VII show the analyses and tensile strength of two samples of cement burnt in a different manner, but made from slurry taken from the same back, that containing the lesser quantity of lime giving the higher results. The Author thinks that, in the majority of cements now in the market, the degree of heat applied, and the time for which it is maintained, result in the production of comparatively rudimentary chemical compounds, in which the excess of silica factors pairs off with an excess of lime, the result being a feeble chemical alliance. When the quantity of lime present is greater than these silica factors will neutralize, a "blowy" cement results. He considers that the cements possessing the most perfect hydraulic qualities are those in which the metamorphosis is most complete, and the most complex chemical compounds result.

The Author, in conclusion, desires to express his thanks to the many friends who have assisted him in the preparation of this Paper, and notably to Mr. Joseph Cash, M. Inst. C.E., engineer and manager of the Brighton and Hove Gas Works; Mr. Arthur J. Jack, Assoc. M. Inst. C.E.; Mr. J. L. Spoor, of Messrs. Hunter, Taylor, and Spoor, Greenhithe; and Mr. Charles Baker, manager of the Reliance Portland Cement Works, Rochester.

APPENDIXES.

APPENDIX I.

ANALYSIS OF PORTLAND CEMENT PRODUCED UNDER THE AUTHOR'S SUPERVISION.

Lime	61·05
Magnesia	0·76
Oxide of Iron	3·19
Alumina	10·10
Potash	0·54
Soda	0·80
Sulphuric acid	0·85
Carbonic acid	mere traces.
Silica	22·22
	99·51

COMPARATIVE ANALYSES IN SEQUENCE.

Constituents.	Chalk.	Clay.	Slurry.	Cement. (Clinker and Powder.)
Carbonate of lime	73·50	1·40	77·57	60·65
Silica (in combination)	..	24·53	7·00	21·85
Silica (free)	0·50	16·49	5·32	0·80
Alumina	0·08	20·60	6·00	8·67
Carbonate of magnesium	0·56	1·89	0·75	1·26
Potash and soda	..	2·90	0·83	0·82
Iron Peroxide	..	5·72	1·64	2·93
Water dispelled at 212° Fahr.	25·00	26·54	..	..
Carbonic acid	..	..	..	0·52
Sulphuric acid	..	..	..	1·18
Sulphides and loss	..	..	..	1·39

APPENDIX II.

Specification for Portland Cement.

The cement to be of a uniform dark grey colour, and to comply with each, and every one of the following conditions and tests:—

The Specific Gravity shall not be less than 3·1, after drying for fifteen minutes in a desiccator at 212° Fahrenheit; and this shall be ascertained by a Schumann, or other approved apparatus.

Tensile Strength.—Not less than twenty sample test-briquettes of approved shape, and of 1 inch by 1 inch, or other approved section, are to be made from the bulk of the different consignments, twelve being gauged neat, and eight with 3 parts of normal sand. They shall be placed in $\left[\frac{\text{fresh}}{\text{sea}}\right]$ water twenty-four hours after gauging, then steeped in $\left[\frac{\text{fresh}}{\text{sea}}\right]$ water six days, and shall, at three, seven, and twenty-eight days respectively, from the date of gauging, successfully resist the following tensile strains applied in a machine to be supplied, or approved by the engineer:—

Neat Cement.	Not less than an Average of	Cement 1 part, Normal Sand 3 parts.	Not less than an Average of.
Days.	Lbs.	Days.	Lbs.
3	180	7	120
7	350	28	200
28	550		

The rate at which the tensile strain shall be applied shall be 100 lbs. in ten seconds. Normal sand shall be quartz sand of approved quality, the whole of which passes through a sieve of 400 meshes per square inch, and the whole of which is retained on a sieve of 900 meshes per square inch.

Over-liming.—The engineer, or his agent, may apply such tests, with a view to determine any excess of lime, as he considers necessary, such as plunging test-pats into fresh water or sea-water immediately on gauging, exposing the same to heat in a wet or dry state, roughly gauging balls of sand and cement with sea-water, and exposing the same immediately in sea-water, &c.

Fineness.—The cement shall be uniformly ground, free from coarse clinker; and samples taken at random shall all pass through a sieve of 1,600 meshes per square inch, and leave a residue by weight of not more than 35 per cent. on a sieve of 5,000 meshes per square centimetre (32,257 per square inch). Should the proportion of residue exceed 42 per cent. on the latter mesh, the cement will be rejected; and if the residue be more than 35 per cent., and less than 42 per cent., the cement may be used, but a proportionate increase in the specified quantity of cement per cubic yard of concrete shall be made.

The contractor, or his agent, may be present at the time of taking the samples from the bulk cement, also when the briquettes are gauged, and subsequently broken, and during every operation necessary to prove the quality of the cement.

Gauging.—The proportionate quantity of water by weight used in gauging shall be correctly recorded, and also the temperature of the air, and that of the cement, at the time of gauging. Observations of the time the cement takes in setting are also to be recorded. Preference will be given to those makers who can produce a chemical analysis of the cement offered, and also an independent record of periodical calcimeter tests, and of tests by compression.

APPENDIX III.

Experiments on Resistance of Portland Cement to Hydrostatic Pressure.

Series A. Experiment to ascertain the best proportions.—A series of cast-iron, 12-inch, double collars were placed on sheet iron, and filled up 3 inches deep with the following mixtures:—(1) cement run in as grout; (2) cement gauged stiff; (3) cement 1 part, fine compo sand 1 part; (4) cement 1 part, fine compo sand 3 parts.

When the mixture was fairly set, the sheet iron was removed, and the collar filled with water, which was therefore free to travel through the cement material. The following Table shows the results obtained:—

Mixture.	Time allowed to set.	Loss of Water in 24 Hours.	20 Days after. Loss in 24 Hours.	Remarks.
	Hours.	Inches.		
1 . .	36	½	Sound	The leakage was between the junction of the mixture and the iron.
2 . .	24	Sound	Sound	
3 . .	48	¾	Slight leakage, bare ⅛ inch.	The leakage was as before, and also through the mixture.
4 . .	72	1	1 inch.	Ditto, mixture very porous.

Series B. To ascertain whether the best mixture in Series A would resist a given head of water.—Mixture 2 was selected, and filled into the end of a flanged spigot pipe of 6 inches diameter, so as to form a plug 6 inches thick. It was allowed to set for forty-eight hours, and then the riser pipe was connected, and water gradually run in until 26 feet head (11·27 lbs. per square inch) was reached. A slight leakage appeared round the junction of the cement and the iron, and also through the cement itself, in the form of beads of moisture, some yellowish discharge forming on the surface of the cement. The loss of water commenced at one pint in the first ten hours, and gradually decreased, until, on the eleventh day, the leakage entirely ceased. Fresh water was used in these experiments; and the temperature of the air varied from 51° Fahrenheit maximum to 42° Fahrenheit minimum.

A further set of experiments were undertaken to ascertain the extent of the penetration of cement deposited on the surface of a mass of rough concrete. A mixture of 1 part cement, 3 parts beach, and 3 parts coarse sand, was filled into a 12-inch cylinder, and allowed to set. A head of 30 feet of fresh water was then applied; and the loss of water per twelve hours was found to be 1·5 gallon at one day, 1·2 at three days, 1·0 at seven days, and 1·0 gallon at ten days.

As this leakage appeared to be constant, the cover of the cylinder was removed, and one pint of dry cement was stirred into the water, and allowed to deposit itself evenly over the surface of the concrete. The loss of water per twelve hours was now 0·85 gallon at one day, 0·80 at three days, 0·80 at seven days, and 0·80 gallon at ten days.

It was found that the cement added had not set, but had the appearance of mud on the surface of the concrete, and probably a similar quantity of clay

would have produced similar results. In practice, the action of the tide would have instantly removed such a deposit of cement grout, there being no sign of penetration or adhesion to the mass.

In another series of experiments, the influence of a thin veneer of cement over the surface of rough concrete in preventing filtration was tested. Cast-iron, spigot, 12-inch pipes were filled with loosely knit concrete, in the proportions respectively of 7 to 1 and 9 to 1, with a plug of concrete to the length of 12 inches. In this state, the porosity of the concrete was extreme, the water flowing through freely. The thinnest possible skin of cement was then floated over the inner face, and allowed to set, the average thickness being less than $\frac{1}{8}$-inch. A head of 30 feet of water was then applied; but there was not the slightest percolation of water at this pressure, proving that such a hydrostatic pressure may be resisted by a skin of cement alone, and also showing the adhesion of the concrete to the iron pipe. The results of these experiments bear out the opinion expressed by the Author in his Paper on "Harbour Improvements at Newhaven, Sussex," that the essential condition to a concrete structure in the sea is "to form a dense skin constituent with the rest of the mass."[1] In order to further test the accuracy of this view, experiments were made by Mr. Cash with concrete of the following proportions: No. 1, Portland cement 1 part, coarse sand 2 parts, gravel 5 parts; No. 2, 1 to 2 to 7. Flanged cylinders, as in the previous experiments, were used, and filled with concrete to a thickness of 12 inches, in the above proportions, gauged with sea-water. When thoroughly set, No. 2 sample was rendered, on the inner face, with a mixture of 3 parts coarse sand and 1 part cement, trowelled on as thinly as possible, No. 1 being left without rendering. A 20-foot head of sea-water was then applied. No signs of moisture appeared on the face of No. 1 until twenty-four hours, and No. 2 remained perfectly dry for fifty hours, after which time No. 1 leaked 165 fluid ounces per twenty-four hours, and No. 2 leaked 5 ounces. The above head of water being maintained, the leakage became gradually less; and on the twenty-second day, No. 1 leaked 10 fluid ounces per twenty-four hours, and No. 2 leaked 2 ounces; and on the fifty-fourth day, the leakage for No. 1 was 42 ounces in twenty-four hours, and for No. 2 it was 4 ounces. The inner, or pressure side of the concrete was clean, the outer, or air surface of the concrete being covered with a white material, an analysis of which is given below.[2] Further experiments were made to test the value of liquid grout when applied to rough concrete. A plug of porous concrete was filled into a cylinder as before. The upper portion of the cylinder was filled with water, and a 5-foot head maintained. Cement grout was then run in, but it did not set, or appreciably reduce the leakage through the concrete,

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 103.

[2] Of this deposit, 6·5 per cent. was soluble in water, and 93·5 per cent. insoluble. The soluble portions consisted of sulphate of magnesia and chlorides of magnesia and soda. The analysis of the insoluble portion was as follows:—

Silica	2·90
Alumina	3·00
Lime	42·56
Magnesia	7·92
Carbonic acid	38·00
Expelled at 212° Fahrenheit	5·62
	100·00

merely forming a mound upon its surface of the consistency of soft mud. Mr. Cash found that the last coat of neat cement rendering (¼-inch thick) of a small gas-tank was lifted and made rotten by the hydrostatic pressure due to a spring breaking out below the tank, whilst the rough rendering (⅝-inch thick) was left intact. This result was subsequently illustrated by covering one end of a tin cylinder with canvas, putting into this a thickness of 1 inch of neat cement of the consistency of dough, and placing the tin in a tank of water. The tin sank in ten minutes, when the finer particles of the cement were found forming a scum upon the surface of a thickness of $\frac{1}{16}$ inch, the cement below being left in a rotten and friable condition.

APPENDIX IV.

Effect of Frost upon Cement Briquettes.

No. 1 *Series.*—Gauged in water of 55° to 60° Fahrenheit, and immersed at a similar temperature, the tensile breaking strain per square inch was 540 lbs. at seven days, and 585 lbs. at fourteen and twenty-eight days.

No. 2 *Series.*—Gauged as above, and exposed for forty-eight hours (setting being unusually slow) to temperatures ranging between 30° Fahrenheit maximum to 22° Fahrenheit minimum; then placed in water exposed in the open air. The temperature during the following five days ranged between 41° Fahrenheit maximum, and 22° Fahrenheit minimum, the briquettes being embedded in ice. After seven days' test, the temperature was slightly above freezing by day, and two or three degrees below at night; but the ice did not thaw on the surface of the water. The tensile breaking strain amounted to 357 lbs. per square inch at seven days, 552 lbs. at fourteen days, and 595 lbs. at twenty-eight days. Cement of specific gravity of 3·125 was used; and the above results are each the average of four briquettes.

APPENDIX V.—Long-Term Tests of Portland Cement.

These tests were made by applying breaking loads to the centres of bars of neat cement, gauged with, and immersed in sea-water. The tests in the first column, in each case, were obtained by gauging cement to the consistency of mortar; those in the second column, in each case, by pouring liquid cement grout into moulds. Tests at 7 days taken as 100.

English Cements.	1 Month.		3 Months.		6 Months.		9 Months.		1 Year.		18 Months.		2 Years.		2¼ Years.		
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	
A . . .	40·9	49·6	63·2	77·6	80·4	108·9	39·9	30·1	42·3	25·2	37·4	13·1					
B . . .	55·7	22·4	92·1	83·5	122·9	88·2	136·6	117·2	132·2	130·1	118·2	104·5	127·7	167·4			Increase per cent. over 7 days' test.
C . . .	78·6	60·8	98·1	117·1	131·9	139·5	162·0	13·9	200·6	24·4	32·9	16·3	88·5	30·2			Decrease per cent. under 7 days' test.
D . . .	14·6	14·8	57·5	60·0	58·5	60·9	58·5	33·9	24·3	23·9	31·7	46·5					
Mean average result . .	47·45	36·9	77·72	84·55	98·42	99·37	99·25	31·82	66·55	26·35	4·05	15·3	108·1	68·6			
French Cements. A . . .	60·7	80·2	43·9	95·7	42·3	90·1	51·3	112·5	46·8	101·1	26·6	86·9	14·4	69·9			
B . . .	131·8	75·6	139·1	96·8	142·8	123·1	129·1	104·5	21·2	33·3	70·4	59·7	76·6	59·7			
C . . .	75·9	57·8	82·2	102·6	91·7	49·5	27·2	54·7	2·2	54·9	42·5	63·3	63·7	60·3	62·1	70·2	
D . . .	70·3	83·9	89·7	98·8	78·3	117·1	82·6	111·8	72·1	111·8	67·2	97·1	84·4	111·5	82·4	74·5	
Mean average result . .	84·67	74·37	88·72	98·47	88·78	94·95	17·65	68·52	23·87	31·17	4·77	15·2	10·37	15·35	10·15	2·15	

APPENDIX VI.—Result of Experiments to show Absorption of Briquettes of Portland Cement immersed in Sea-Water.

These results are in each case the average of six tests, and were obtained by gauging with fresh-water briquettes of 1 square inch section, and immersing the same at the Pier-Head, Newhaven Harbour, forty-eight hours after gauging.

Temperature of Cement and Air 57°; Residue 10 per cent. on 50 × 50 mesh.

Proportion of water by weight $\frac{\text{Neat}}{7\frac{1}{2}\text{ to }40}$ $\frac{1\text{ to }1}{7\frac{1}{4}\text{ to }40}$ $\frac{1\text{ to }2,\ 3,\text{ and }4\text{ respectively.}}{7\text{ to }40}$

Table of Average Weights and Breaking Strains in Tension.

Proportions.	14 Days.			28 Days.			3 Months.			6 Months.		
	Before Immersion.	After Immersion.	Breaking Strain.	Before Immersion.	After Immersion.	Breaking Strain.	Before Immersion.	After Immersion.	Breaking Strain.	Before Immersion.	After Immersion.	Breaking Strain.
	Grammes.	Grammes.	Lbs. per Sq. Inch.	Grammes.	Grammes.	Lbs. per Sq. Inch.	Grammes.	Grammes.	Lbs. per Sq. Inch.	Grammes.	Grammes.	Lbs. per Sq. Inch.
Neat	227·5	238·8	446·7	213·8	219·6	570·0	213·7	216·3	448·3	212·8	239·5	495·0
1 to 1.	233·2	243·7	255·0	215·7	220·6	291·7	217·2	218·0	299·2	228·2	250·0	348·3
1 to 2	227·0	238·5	123·3	212·2	217·0	166·7	212·5	213·6	185·0	219·5	239·9	242·5
1 to 3	221·5	235·2	..	203·2	207·8	..	205·9	211·1	135·0	210·7	232·2	195·0
1 to 4	211·2	222·2	..	206·7	211·7	..	205·1	212·1	..	190·5	214·8	142·5

APPENDIX VII.

RESULTS OBTAINED FROM BURNING, IN A DIFFERENT MANNER, TWO SAMPLES OF SLIP FROM THE SAME BACK.

—	Sample A.	Sample B.
Carbonic acid	0·35	1·25
Magnesia	0·65	0·75
Insoluble silica	1·50	2·84
Soluble silica	20·80	19·50
Alumina and ferric oxide	16·25	12·50
Lime	54·85	56·55
Alkalies and loss	5·60	..
Alkalies and loss, with traces of sulphate of lime	..	6·61
Total	100·00	100·00

Tests.	Sample A. Lbs. per Inch.			Sample B. Lbs. per Inch.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Neat cement—						
7 Days in water .	600	580	593½	450	390	420
14 ,, ,,	660	640	647½	500	450	470
28 ,, ,,	850	750	783⅓	600	500	551⅔
3 *Standard sand to 1 cement—*						
7 Days in water .	240	220	223⅔	120	100	108½
14 ,, ,,	300	250	261⅔	165	150	153⅔
28 ,, ,,	430	370	383⅓	190	160	175

APPENDIX VIII.

Fancy Tests.

Some discussion has taken place as to the advantage of adding sugar, salt, or soda to concrete. The following comparative tests in compression, at three months, have been undertaken to ascertain what effects result from the addition of varying proportions of these materials. The same sample of cement was used throughout the trials; it had a specific gravity of 3·030 (weight, 113 lbs. per bushel), and was ground to leave a residue of 9½ per cent. on a 50 by 50 mesh sieve. The following Table gives the average tests in tension and compression:—

Conditions.	Neat. Average per Square Inch. Tensile Strain.	3 Standard Sand to 1 Cement. Average per Square Inch. Tensile Strain.	Average Crushing Strain at 3 Months. Per Square Inch.
	Lbs.	Lbs.	Lbs.
28 Days' immersion in fresh water . . .	574	192	*Neat*— 7,392
3 Months' immersion in fresh water .	Did not break at 600 lbs.	216	*3 Standard Sand to 1 Cement*— 2,112

Addition of Sugar.—Six compression blocks of 8 square inches were gauged with 20 per cent. of fresh water, and with the addition of 5 per cent., by weight, of common brown sugar. Three of these fell to pieces in the water, or in adjusting in the machine. The remaining three gave an average breaking strain of 2,557 lbs. per square inch.

Six compression blocks of 16 square inches, of 3 of standard sand to 1 of cement, were gauged with 10 per cent. of fresh water, and with the addition of 5 per cent. of sugar as before. Three of these broke in adjusting in the machine, and the remaining three gave an average breaking strain of 1,358 lbs. per square inch.

Twelve compression blocks (six with, and six without sand, as above) with 2½ per cent. of sugar all fell to pieces; and the contraction was more marked with these samples than with those containing 5 per cent.

In all cases, a large quantity of gelatinous tasteless substance was exuded from the blocks. In setting, the blocks contracted greatly, more especially the samples without sand.

Addition of Soda.—The following Table gives the average results obtained with the addition of 2½ per cent. and 5 per cent. respectively of common washing soda.

Composition of Blocks.	Area of Blocks.	Average Crushing Strain per Square Inch.	Conditions.
	Square Inches.	Lbs.	
Neat Cement— 2½ per cent. soda. 20 per cent. water	8	2,862	3 Months' immersion in fresh water.
Neat Cement— 5 per cent. soda. 20 per cent. water	8	2,841	"
3 *Standard Sand to 1 Cement—* 2½ per cent. soda. 10 per cent. water	16	855	"
3 *Standard Sand to 1 Cement—* 5 per cent. soda. 10 per cent. water	16	1,241	"

Addition of Common Salt.—The following Table gives the average results obtained with the addition of 2½ per cent. by weight of common salt in solution.

Composition of Blocks.	Area of Blocks.	Average Crushing Strain per Square Inch.	Conditions.
	Square Inches.	Lbs.	
Neat cement, and 20 per cent. water	8	3,590	3 Months' immersion in fresh water.
3 standard sand to 1 cement, and 10 per cent. water	16	932	"

III.

(*Paper No. 2373.*)

"The Influence of Sea-Water upon Portland Cement Mortar and Concrete."

By WILLIAM SMITH, M. Inst. C.E. (of Aberdeen).

THE object of this Paper is to place on record investigations made in connection with the deterioration of some of the concrete work at Aberdeen Harbour, which have more than a local or transitory interest. In the correspondence on "Concrete Work for Harbours" the Author mentioned among the destructive influences bearing on the south breakwater at Aberdeen Harbour since its construction in 1872 "the disintegration of the surface of the concrete by the chemical action of the salt-water on the Portland cement."[1] The softening of the concrete face of the wing walls at the entrance to the graving dock led to a thorough investigation of the chemical nature of this disintegration.

The graving dock was built on a site reclaimed from the Albert basin, by the erection in it of 1,000 lineal feet of quay walls, made of plastic concrete, surmounted by concrete deposited *in sitû* and faced with granite ashlar. With a view to economy, Portland cement concrete was adopted for the whole of the works, with rubble stone added to still further reduce the cost. The concrete for the entrance works, caisson chamber, dock-bottom, and the head of the dock, was composed of 1 part of cement, 3 of sand, and 3 of stones, with rubble added; the concrete for the side walls, 13 feet thick, consisted of 1 part of cement, 4 of sand, and 4 of stones, with rubble; that for the foundations of the wing walls, of 1 part of cement, 3 of sand, and 4 of stones; for the fine concrete facing, from $3\frac{1}{2}$ feet to 12 feet above datum, the proportions were 2 parts of cement, 3 of sand, and 4 of stones; and for the concrete backing of the wing walls, 1 part of cement, 3 of sand, and 6 of stones. The altar steps, and the upper part of the wing walls were faced with granite ashlar. The plastic concrete composing the lower part of the quay walls, was specified somewhat similarly to the wing walls, with a fine concrete facing; but experience of this method of deposit at Provost

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 224.

Jamieson's Quay showed that the water fluxed the slightly set concrete, and spread the contents of the skips of fine facing concrete throughout the frame. To prevent the formation of horizontal layers of fine and coarse concrete, the specification for both walls was altered to "a homogeneous mass of concrete deposited inside frames, composed of 1 of cement, 2 of sand, and 3 of stone for one-third of the depth of the frame, and of 1 of cement, 3 of sand, and 4 of stone in the upper two-thirds." The order for this alteration, which consisted essentially of an addition to the strength of the concrete in the foundation of the wall, to compensate for waste of cement in commencing to fill the frame, was erroneously supposed by the Inspector of Works to be applicable also to the wing walls, which were thus by mistake built without the fine concrete facing. The alteration involved the use of a larger quantity of cement than would have been required by the specified arrangement; and immediately on being built, the surface was plastered. The length of the wing walls is 94 feet. The whole area of the bottom and top of the floor, and the back of the side walls up to the level of the surface of the floor, were specified to have a "watertight" lining composed of 3 parts of clean, rough, sharp sand to 1 of Portland cement, and to be 4 inches thick. This was adhered to for the underside of the bottom; but the upper surface of the floor, and the back of the walls were made much stronger, and covered with a really watertight mixture.

When the dock was opened, it was found that the leakage amounted to the flow through one safety-valve in the culvert commanded by about four hours' pumping of an 8-inch centrifugal pump per 24 hours. The leakage gradually increased, however, coming through the mortar of the concrete walls, and the entrance walls began to swell, opening the joints of the sill stones, and cracking the plaster. In June, 1887, about two years after the opening of the dock, the Author reported "that the Portland cement concrete entrance walls have expanded $2\frac{3}{4}$ inches on the height of the walls, their surfaces have cracked and bulged, and the joints of the caisson quoin stones have opened up, causing considerable leakage." As the damage appeared to be due to chemical action on the Portland cement, Professor Brazier, of Aberdeen University, was consulted on the subject. He reported to the Author, in June, 1887, that

"the analyses of the series of decomposed cements show a remarkable difference to the original cement, inasmuch as that in all these samples there is found a large quantity of magnesia, and a large proportion of the lime in the form of carbonate. I believe this alteration is brought about entirely by the

action of sea-water upon the cement. There is no other source for either the magnesia or the carbonic acid." [1]

Tables are given in Appendix I showing the constitution of the original cement, and of the decomposed cements, as analyzed by Professor Brazier. The results of a further series of experiments obtained by digesting Portland cement in a variety of solutions are given by Professor Brazier in a letter to the Author, dated 19th November, 1887 (Appendix II).

When the matter was reported to the commissioners in May, 1887, no damage or decomposition was observable at low water on the north wing wall of the dock. Even in July, the damage, so far as it was noticeable at low water, was confined to the south wing wall, the caisson chamber, and the entrance walls. It was then reported by the Author that,

"the rapidity of the chemical action of the sea-water on the south wing wall, as compared with the north wing wall, was due to the unbalanced pressure of the water on the south wing wall when the dock is emptied of water. This caused a current of sea-water through the porous concrete structure, which continually washed the decomposed cement into the dock, and brought new particles of concrete and sea-water into contact." [2]

In July, 1887, Mr. Philip J. Messent, M. Inst. C.E., was requested to visit Aberdeen and report as to the cause of the damage, and the steps to be taken for remedying the defects. Mr. Messent reported on the 24th of November, 1887, that "it appeared that the deterioration was chiefly confined (so far as could be ascertained by examination) to the concrete which contained the largest proportion of sand, viz., three to one and upwards. The plaster composed of one of cement to one-and-a-half of sand was generally hard, as were the lower portions of the wing walls, as well as the portions of the culverts above mentioned" (composed of 1 of cement, 2 of sand, and 3 of stones).

The report and analyses made by Mr. Pattinson, public analyst of Newcastle-upon-Tyne, of samples of concrete and plaster, from the Aberdeen graving dock, sent to him by Mr. Messent, are given in an Appendix to Mr. Messent's report, and substantially confirm those by Professor Brazier. The conclusions arrived at by Mr.

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[1] Details of this report are given in Mr. P. J. Messent's Report as to "The Cause of Damage to the Aberdeen Graving Dock," dated November 24, 1887, a copy of which is in the Library of the Institution.

[2] Report by the Author to the Aberdeen Harbour Commissioners, 19th July, 1887.

Pattinson will be found in Appendix III. Mr. Messent remarks with reference to these analyses that,

"In their examination of the deteriorated concrete, both agree that the presence of too much magnesia in the cement is the cause of the deterioration; and that, as the same proportion or quantity was not found in the briquettes made of the neat cement used, the additional quantity found in the spoiled concrete must have been supplied by the sea-water, in contact with the cement portion of the concrete, which sea-water, whilst precipitating the magnesia that it contains, takes away in an altered form a portion of the lime from the cement."

Mr. Messent made experiments as to the quantity of sea-water absorbed by briquettes of neat cement, and by briquettes made of cement mortar of 1 part of cement to 3 of sand, and found that, by repeated absorption and drying, the solids contained in the sea-water were left in the briquettes, and the strength of the cement diminished in the neat cement briquette 69·64 per cent., and in the 1 to 3 mortar briquette 36·8 per cent. He also made the following experiments, with the view of ascertaining the effect and relative extent of the percolation of sea-water through cement mortar.

"I took two briquettes, one of neat cement and one mixed one to three, and having procured two 1-gallon glass bottles with mouth and neck of about $1\frac{3}{4}$ inches internal diameter, I secured over the mouth of each bottle one-half of each briquette in such a manner that any water entering the bottles must pass through the half-briquettes. They were then loaded and suspended by lines from a craft afloat in Shields harbour; the depth of their immersion being about 18 feet, giving a pressure on the briquettes of about 8 lbs. per square inch. They were raised several times to allow the compressed air (if any) to escape, and after actual immersion for about eighty-seven hours they were taken up,......and it was found that about 94 ozs. of water had passed through the mixed, one to three, half-briquette into the bottle, and only 1 oz. had passed through the neat cement half-briquette."

The analyses by Mr. Pattinson of the two halves of the 3 to 1 briquette, and of the sea-water in the bottle and in the sea, are given in one of the Appendixes to Mr. Messent's report, and they are summed up in the following words:

"A distinct amount of lime has been removed from the briquette through which the $94\frac{1}{2}$ ozs. of sea-water had passed, and a very marked increase in the amount of magnesia is found in the same briquette, about two-and-a-half times more than is found in the original briquette which had not been brought into contact with sea-water. These results show that the chemical action between sea-water and cement indicated in my last report to you actually takes place; that is, that the lime of the cement precipitates, as hydrate, the magnesia of the magnesium chloride and sulphate contained in sea-water, with the consequent formation of calcium chloride and sulphate. If the cement or concrete is con-

tinually brought into contact throughout its substance with fresh portions of sea-water there will be a continued deposition of hydrate of magnesia and probably sulphate of lime, and removal of lime, necessarily resulting in the disintegration and destruction of the concrete."

Mr. Messent observes, with reference to the results of the analyses, that,

"The effect of the percolation was thus to increase the percentage of magnesia in the mixed briquette by 1·05, equal to an increase on the cement portion (one-fourth of the whole briquette) of over 4 per cent. in eighty-seven hours of forced percolation."

In a subsequent paragraph of his Report Mr. Messent states,

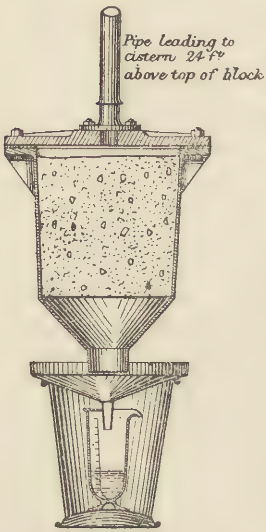
"I am of opinion that the cause of the damage referred to is the injurious effect of sea-water, which entered through holes in the plaster,....percolated the concrete of the intermediate portion of the wing walls, and of the mass behind the altars of the dock walls, and in so percolating extracted lime from, and deposited magnesia in, the cement portion of the concrete, causing it to deteriorate and expand; and that the injurious percolation was facilitated by the inappropriate relative proportions of the cement, sand, and stones, or the insufficient quantity of cement in the original composition of the deteriorated concrete."

Mr. Messent's experimental investigations not only confirm the Author's opinion that the damage to the graving dock, by the chemical action of sea-water on the Portland cement, has been accelerated by the pressure of the water on the porous concrete of the dock, but they also suggest the obvious remedy and prevention of that action, in such works, by the formation of impermeable concrete or masonry. The whole of the specimens investigated, both at the south breakwater and the graving dock, were taken from concrete blocks, which had been made in Messent's mixers, deposited in the usual manner above water, and allowed to set over six months before immersion.

To test the permeability of concrete made of various proportions of materials, the Author constructed a pair of cast-iron boxes (*Fig. 1*) to mould and contain each a cubic foot of concrete. The boxes are cast with a conical bottom terminating in a square pipe, and are fitted with watertight covers with shoes to receive the ends of vertical pipes. These pipes lead up to a cistern placed 24 feet above the top of the block, and containing sea-water which filters through the concrete and is collected at the bottom of the box. The results of these experiments, which are given in Appendix IV, show that to obtain an impermeable concrete, (1) the cement must be finely ground; (2) it should not be weaker than 1 of cement to 6 of sand and stones; and (3) the concrete

should have sufficient time, at least three months, to set before the application of the pressure. If any of these conditions are lessened, a corresponding increase must be made upon the others. The 1 to 6 experimental blocks being made of selected materials carefully mixed, the concrete required to give equal results in the works had to be stronger, generally 1 to 5. The apparent inconsistency of the results, where all the experiments were made carefully with no leakage past the sides of the concrete, point to the conclusion that only the worst results, in the cases of finely-ground and coarsely-ground cement respectively, should be relied upon. The principal defect of concrete work in general is the irregularity of the results in mixtures that are nominally alike; and a considerable margin of strength is therefore required even in carefully made experiments, and much more in actual work. The anomalous result of No. 7, which, although it had been kept three times as long, and was made of finer cement, was worse than No. 1, may be due to the greater porosity of the concretes as distinguished from the permeability of the mortars. The porosity of the concrete, including accidental voids between stones and mortar, as well as the permeability of the mortar, is the property against which provision must be made in actual concrete work.

Fig. 1.



APPARATUS FOR TESTING THE PERMEABILITY OF CONCRETE.

According to Professor Brazier, the cause of the expansion of concrete when subjected to the chemical action of sea-water, appears to be the formation of a more bulky compound of magnesia and lime with carbonic acid, and especially with sulphuric acid and water, in place of the lime of the cement. The chemical equations for the action of the lime in the cement upon the magnesian salts in sea-water are:—

$$Mg'' Cl_2 + Ca'' H_2 O_2 = Mg'' H_2 O_2 + Ca'' Cl_2$$

Magnesium chloride + Calcium hydrate = Magnesium hydrate + Calcium chloride.

$$Mg'' S O_4 + Ca'' H_2 O_2 = Ca'' S O_4 + Mg'' H_2 O_2$$

Magnesium sulphate + Calcium hydrate = Calcium sulphate + Magnesium hydrate,

the sulphate of lime crystallizing with water as—

$$Ca'' S O_4 + 2 H_2 O = Ca'' S O_4, 2 H_2 O,$$

Calcium sulphate + Water = Hydrated calcium sulphate,

a substance of great bulk compared with the lime base.

The lime of the cement takes up the free carbonic acid from the sea-water, forming carbonate of lime; the sulphate, carbonate, and hydrate of magnesia in the sea-water react with the lime, forming a deposit of magnesia and hydrated sulphate of lime, which, being bulkier than the lime base, causes swelling and disintegration of the concrete, while the magnesia destroys the adhesive power of the cement. It is very improbable that magnesia is present in the Portland cement, and causes swelling of the concrete by the absorption of water; for where the cement is subjected to the ordinary mechanical tests, a large proportion of magnesia would betray its presence by reducing the adhesive strength. Magnesia, in a minute state of subdivision, could not escape hydration on the mixture of the cement with water. There is no doubt that, in permeable concrete, the whole of the lime forms a base on which carbonic acid and the salts contained in the sea-water act chemically; that the resulting deposit occupies a larger space than the lime base; and that the force of chemical action exceeds the adhesive power of the cement, thus effecting the rupture of the mortar and expansion of the mass of concrete. In concrete made with a small proportion of sand, the stones are united by a cement mortar of great adhesive strength; and the voids left by the absence of mortar in intersticial spaces are filled with a creamy white substance, formed chiefly by the action of free carbonic acid and magnesia from the sea-water on the walls of the cells. Where the voids do not communicate with the sea through a very permeable mortar, or under unbalanced pressure, the first filling is not renewed, and chemical action ceases. It is possible that where the mortar is of good strength, its adhesive power may balance the chemical force for a time. The sudden access of water under pressure to concrete containing voids, reveals the presence of decomposed cement by white clouds of magnesia and carbonate of lime in the escaping liquid. The immediate cause of swelling in concrete is the want of adhesive strength in the mortar to resist the disruptive force of the chemical action of sea-water on the Portland cement.

Setting of Cement.—It is evident, from the certainty and readiness with which chemical action is set up between the lime contained in Portland cement and certain constituents of sea-water, that the union of the lime with the silica, or silicates, which was supposed to take place on the addition of cold water, if a chemical combination, is exceedingly feeble. It is more probable that slaked lime develops the adhesive property of cement when minutely subdivided with silica, alumina, and iron, than that it should require the destruction of a silicate of potash or soda, the formation of silicate of lime, the partial decomposition of silicate of alumina and iron, and the formation of double or treble hydrated silicates of lime, alumina, and iron, to cause setting. But the absorption of water is not confined to the lime in the cement; and probably the adhesive property of Portland cement is due simply to the restoration of the water of crystallization to the lime and alumina.

The degree to which cement clinker should be burned appears still undecided by chemical investigation, and is determined by experience. The driving off of carbonic acid and water are the essential objects of burning both natural and artificial cements; the decarbonization of the lime, and the dehydration of the lime and alumina may be verified by analysis as essential to the formation of cement. The decomposition of the clay, to separate the alumina from the silica and make the latter soluble in water, is said to be another object of burning; but what "those combinations of silica, alumina, and lime, which require a very high temperature for their production,"[1] may be, has not been defined. The decomposition of the clay appears to be the essential object of high burning below 2,000° Fahrenheit, to set the alumina free from the silica so that it may crystallize freely with the lime on the addition of the water of crystallization. In a low-burned cement, the lime is probably the only constituent free to crystallize with water, which is shown by the under-burnt cement flying in cracks and blisters like a mixture of lime and brick-dust. The under-burning of cement clinker does not appear to be discoverable by analysis, but it may be detected with certainty by the usual mechanical tests. The sieve for fineness, twenty-eight day mortar tests for strength, and the "thin pat on plate" tests for heat or under-burning, appear sufficient to ascertain the quality of cement, for none that is bad or adulterated, or unsuitable for sea works, can pass these tests.

[1] Dent's Cantor Lectures, 1887.

Detrimental Constituents in Cement.—The presence of hydrate of magnesia in disintegrated Portland cement concrete leads naturally to the conclusion that magnesia is a very undesirable constituent. It does not necessarily follow, however, that it cannot be present innocuously; nor can it be argued that the presence of magnesia originally in the cement is likely to cause disintegration. Hydrate of magnesia, or mixtures of hydrate of magnesia with lime or carbonate of lime, are not cementitious substances; and the presence of magnesia diminishes the adhesive property of cement. The tendency of magnesia and its compounds in solution, on a glass slide, is to roll off like quicksilver; while their precipitates have a hard gritty feeling when touched, which is the antithesis of the satiny feeling of cements. The latter appear to be of a sticky nature on a microscopic slide, and present a simple crystalline structure, very different from the amorphous grains of magnesia and its compounds separated out of disintegrated concrete. But notwithstanding the repellent nature of magnesia and its affinity for water, the magnesian hydrate found in concrete could not have affected the strength had it been originally present. All the chief constituents of cement dehydrated in the kiln reabsorb water greedily, first from the water in the air in slaking, and afterwards on admixture with water. Calcined magnesia finely ground, or in the precipitate powder, absorbs water as freely as lime or alumina; and having taken up its equivalent, becomes inert. That hydration should commence again after the setting of the cement is only probable on the assumption of the magnesia having less affinity for water than the lime and alumina, which would thus dehydrate it during the process of setting. From experiments made by Mr. Henry Thomas Jones, of Aberdeen University, the rate of absorption of water by the oxide of magnesium is as follows:—

100 parts magnesium oxide, $Mg\,O$, absorbed—

(*a*) In twenty-four hours	36·00
(*b*) In forty-eight hours	38·74
(*c*) In nine days	44·30
Theoretical maximum	45·00

the hydration of magnesium oxide being in these experiments more rapid than that of Portland cement. The Author mixed dehydrated oxide of magnesium, with Portland cement in the proportion of 5 per cent. by weight. The briquette, broken at nine days, showed a tensile strength of 277 lbs. per square inch, indicating a loss of strength of about 20 per cent. due to the presence of the magnesia. Briquettes of 1 to 3 mortar, with the same proportion of magnesia in the cement, broken at

twenty-eight days, gave 162 lbs. on the square inch. There was no appearance of subsequent hydration, or softening, on the re-immersion of the briquettes.

The presence of sulphuric acid in cement which has been calcined in the course of manufacture, may be injurious. The formation of "dead-burnt gypsum" takes place at a temperature ranging between 200° and 500° Fahrenheit.

"The gypsum is burnt dead at the temperature employed in making the cement, and does not combine with water until after the rest of the mass has hardened; and then, as it slowly takes up water and expands, it causes the whole to crumble. After it has been heated to 500° Fahrenheit, it also combines with water very slowly, the combination going on for several weeks; but the product is a hard mass, which is translucent like alabaster, and more dense than ordinary gypsum.[1] If it is then heated to 150°, it passes into the condition of ordinary burnt gypsum."[2]

The temperature to which the cement clinker is raised is generally far above that of the "dead burning" of gypsum; and the temperature to which it is afterwards raised in the process of grinding is no doubt sufficient to make the calcium sulphate pass from the highly-burned condition, into the state of ordinary gypsum. Thus the theory of injury accruing to Portland and Roman cement concrete from the presence of sulphuric acid, or rather of dead-burnt gypsum, is far from being established, either by chemical science or the practical observation and experiments of engineers.

The Roman cement used for repairing the south breakwater at Aberdeen, under water, contains a large proportion of sulphuric acid, without detriment so far as four years' experience shows. The analysis of this cement, made by Professor Brazier, is as follows:—

Constituents.	Percentage.	Deducting last Item.
Alumina and oxide of iron	22·20	24·66
Silica	23·63	26·35
Lime.	41·24	45·82
Magnesia	0·63	0·70
Sulphuric acid	2·23	2·47
Moisture, carbonic acid, &c.	10·07	..
	100·00	100·00

[1] "Dingl. Polyt. Journ." vol. cci. p. 254.
[2] *Ibid.* vol. ccii. pp. 52 and 355.

Particulars of the sand and stones used for concrete work at Aberdeen are given in Appendix V.

Remedial and Preventive Measures.—The coating of carbonate of lime formed on the surface of concrete blocks or masses of concrete, on exposure to the air, has been supposed to protect them from the chemical action of sea-water. It was noticed that until the water passed through the skin of the concrete, no swelling or serious damage took place; and the formation of the coating of carbonate of lime, either in the air or in sea-water, was connected with this fact. Some authorities even recommend the exposure of the blocks to the air for several months previous to immersion, to allow of the formation of a film of carbonate of lime; and in case the progress of the building should not allow sufficient time for the natural process, they suggest that a film might be formed by washing the block with a solution of commercial carbonate of ammonia (sesqui-carbonate of ammonia). The fact that the cause of the chemical action of sea-water on concrete is the forcing of the sea-water through permeable mortar by an external force, demonstrates the futility of the carbonate of lime film, which is itself more permeable than the mortar on which it is formed. The mistake arose from the formation of the deposit being only observable on an approximately watertight skin of mortar or plaster. The free carbon dioxide in sea-water (which amounts to 0·0479 gramme in 1 litre of water, or 0·005 per cent.)[1] forms a film of carbonate of lime on the skin of all immersed concrete, and ultimately destroys it. Mechanical attrition assists this kind of chemical action, by the repeated exposure of fresh surfaces to the sea-water; but the thickness of the film, increasing with the time of exposure, shows that the coating of carbonate of lime is in itself no protection to the concrete from chemical action.

The exclusion of sea-water by a coat of Portland cement mortar plaster, practically watertight, cannot be regarded as a permanent or a certain protection. The fracture of any portion of such a covering, or the penetration of sea-water to the body of the concrete from any part accidentally omitted in plastering, or through adjacent blocks, permitting a slight degree of chemical action in the mass, although the softening may not be apparent, swells the concrete, parting the surface of the plaster in hair-cracks, which, though scarcely perceptible, admit more water to the body of the concrete and hasten its disintegration. The practical difficulty of making concrete walls watertight by

[1] "The Voyage of the 'Challenger,'" by Sir C. Wyville Thomson.

plastering can only be appreciated by experience, quick-setting cement being unsuitable for this description of work, owing to its tendency to part on the surface in hair-cracks under the float used for smoothing it; while a slow-setting cement is inapplicable to vertical walls. A lining of fine concrete, 2 or 3 feet thick, is more satisfactory when carried under the foundations and up the back and front of the wall, the internal porous mass being filled in simply as hearting. But the penetration of sea-water by accidental openings through adjacent masses of concrete, as in the case of the graving dock side walls, by causing the hearting to swell, cracks the fine concrete or masonry lining, the chemical force overcoming the resistance of a considerable thickness of fine concrete or ashlar masonry.

The works recommended by Mr. Messent for the repair and protection of the graving dock were as follows:—

"If the water is prevented from entering from the front, further damage or deterioration would be prevented, and I have no doubt that a very large proportion of the concrete is as yet uninjured, whilst much of what is partially deteriorated is still strong enough for its required purpose, so long as it is protected from the effect of further sea-water percolation. With this object, the works of repair and protection that I recommend are chiefly confined to the outside entrance and wing walls. They consist of an additional apron, made of concrete, composed of one Portland cement, one-and-a-half sand, and four-and-a-half gravel, enclosed by sheet piling at least 10 inches thick, 18 feet long, with outside waling, tied to the present apron and wing walls by wrought-iron bolts at 5 feet intervals. The facing of the wing walls should be taken down, probably for a depth of 2½ feet from the face, so as to remove the deteriorated portions of the concrete, and be refaced from the foundation to the under side of present granite facing, by coursed granite rubble, backed with random rubble, set in Roman cement mortar. The coursed rubble to consist of two stretchers to one header, and to average in depth 1½ feet, whilst the average of the coursed and random rubble should be 2½ feet deep, to be properly stepped and bonded to the existing concrete, and returned for the whole thickness of the walls at the ends next the harbour quay walls. The present ashlar facing of the upper portion of the wing walls to be rebuilt with Roman cement mortar, any deteriorated concrete behind to be taken out and replaced by random rubble in Roman cement mortar. . . . . The sides of the caisson chamber to be faced with granite coursed rubble, 9 inches thick, with random backing, stepped and bonded into the concrete, after the removal of the deteriorated portions. Those portions of the culverts that pass through the entrance and wing walls should be faced by coursed granite arch, side, and invert stones, averaging 1 foot in thickness, replacing the deteriorated concrete previously removed. The present outside apron, with the proposed addition to the apron, to be covered with a paving of granite sets, 9 inches thick, set, bedded, and jointed in Roman cement mortar. The outer sill between the granite quoins to be similarly paved, any defective concrete found being removed and replaced by rubble in cement."

These recommendations were carried out, Portland cement being

substituted for Roman during the course of the work, with Mr. Messent's concurrence, on seeing the dry state of the walls when enclosed within the cofferdam.

The only certain and permanent method of building large masses of concrete or masonry for immersion in sea-water under variable pressure, is to make the entire mass impermeable. It thus becomes a question of comparative expense, whether Portland cement concrete may be more suitable for any work in sea-water than masonry. It is evident that a large margin in the proportion of the more expensive materials, must be allowed, in concrete building, for imperfect mixing and distribution, and that the weakest proportion of cement to ballast which can be considered permanently safe, under the pressure of sea-water, is 1 to 4, or say 1 part of cement, $1\frac{1}{2}$ of sand, and $2\frac{1}{2}$ of stones. The same mortar used in building blocks of rubble masonry would only amount to one-third, instead of one-half of the mass, the proportion being 1 part of cement, $1\frac{1}{2}$ of sand, and 5 of stone, or 1 of cement to $6\frac{1}{2}$ of sand and stone.

The prices of these materials and labour will vary with the locality. At Aberdeen they compare as follows :—

PORTLAND CEMENT CONCRETE 1 to 4.

	Per Ton. s.	d.		Per Cubic Yard. £	s.	d.
Cement	35	0	=	0	9	4
Sand	2	0	=	0	0	$11\frac{1}{2}$
Screened gravel	3	8	=	0	3	0
Labour and framing				0	6	$10\frac{1}{2}$
				£1	0	2

RUBBLE MASONRY $1 + 1\frac{1}{2} + 5$.

	Per Ton. s.	d.		Per Cubic Yard. £	s.	d.
Cement	35	0	=	0	6	$2\frac{1}{2}$
Sand	2	0	=	0	0	$7\frac{1}{2}$
Rubble	3	0	=	0	3	3
Labourers, $1\frac{1}{4}$ day at 3*s.* 4*d.* =				0	4	2
Mason, 1 day at 5*s.* 5*d.* =				0	5	5
				£0	19	8

Whether made of concrete or of masonry, the blocks should be bonded and built as headers and stretchers like ordinary ashlar masonry; then the water and air should be excluded by caulking the face joints, and filling the whole of them with cement grout,

made with either Roman cement or equal measures of Roman and Portland cement for work under water, and Portland cement, lime, and sand for work above water. There should be no flat or concave horizontal surfaces where sea-water may lodge; for no mortar, however strong or impermeable, appears to withstand the chemical action of sea-water when exposed to soaking and evaporation in the sun.

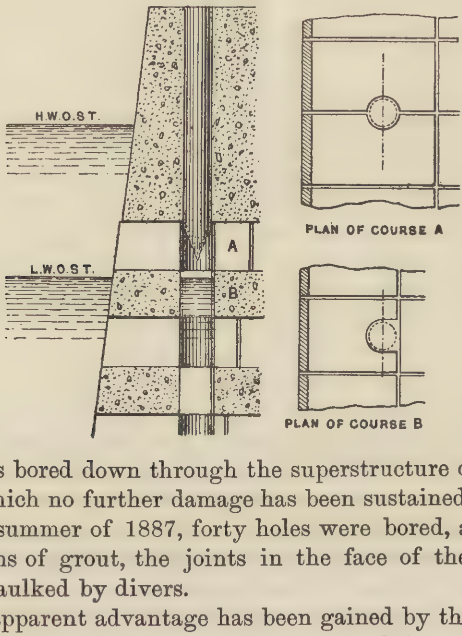
The practice during the last thirty years in sea works has tended towards increasing the size and weight of concrete blocks, trusting to the stability of individual blocks for the durability of the structure. Bond has in many cases been ignored, and even avoided, on the plea of allowing for unequal settlement. At Aberdeen Harbour there are two kinds of dry ashlar work in the north pier, the older part by Smeaton laid in horizontal courses, and that more recently constructed on Telford's design in inclined courses. The walls in both cases are backed with rubble and ballast hearting, liable to be swept away by the water flowing in and out through the joints of the ashlar face during the passage of waves along the pier. The voids left behind the ashlar appear to be dangerous, chiefly because the sudden compression of the air in them blows out the ashlar facing stones, a frequent occurrence in the horizontal coursed wall, but rare in the inclined courses. The same effect of the sudden compression of air occurs in the south breakwater, as described by the Author,[1] where the concrete blocks, eight times the weight and ten times the bulk of the ashlar stones in the north pier, proved more liable to removal from this cause.

While examining three cavities in the surface of the south breakwater, in June, 1887, the Author was struck by the fact that each of them was opposite the vacancy left by the eating away of a pile by sea-worm, and that they were each formed, entirely under low water, by the fracture and blowing out of blocks in two or three courses (*Fig. 2*). He tried the remaining parts of the fractured blocks with a pick, and found them quite sound, and only sufficiently softened to admit the point of the pick about an inch at a blow. Thus, although the concrete blocks had softened considerably by chemical action, they were still sufficiently hard to require an enormous and suddenly applied force for their fracture. The volume of air confined in the upper part of the cavity left by the pile could not have exceeded 12 to 14 cubic feet. The pressure per square inch of this volume of air, however, was trans-

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 224.

mitted by the water to the backs of the blocks adjacent to the tube; the total pressure being increased in the proportion of the area of the surface of the blocks to that of the water. The accumulated pressure in the cavity, although tending to expel the water by the fissures at which it entered, would attain its maximum before this was effected to a material extent, and the blocks would be blown out. The spaces left in the interior of the breakwater, by the eating away of the piles, thus formed a series of hydropneumatic accumulators which, as the blocks became weakened by chemical action, were exposed to the bursting out of their sides under the action of storm-waves. During the summer of 1886, the portion of the breakwater which had sustained the greatest damage from this action was grouted up solid, through

Fig. 2.



sixteen holes bored down through the superstructure of concrete *in situ*, since which no further damage has been sustained at this part. During the summer of 1887, forty holes were bored, and filled up with 212 tons of grout, the joints in the face of the breakwater being first caulked by divers.

Thus no apparent advantage has been gained by the increase of the size of the blocks in constructing the south breakwater. The destructive force at work on the small ones in the north pier was not excluded from the south breakwater; and whilst the weight of each block was increased, from a little over 1 ton on the north pier, to 12 or 18 tons, the size was increased in a greater ratio; and the air received accommodation specially adapted for destructive compression, and was assisted by the chemical action of

the sea-water upon the Portland cement concrete blocks. Where the ashlar facing of the north pier has been rebuilt with Portland and Roman cement mortar, it has not given way again.

The increase in the size of blocks used in the construction of sea works has become almost fanciful. Heavy plant for handling and building large blocks is not available for small harbour works; and while the heavy block system may be economical for great sea works, it is unfortunate for smaller harbours that the stability of these sea works should be considered due to the use of blocks weighing 45 tons and upwards, if it really depends on the perfect homogeneity of the whole structure obtained by bond and grout. The chemical action of sea-water has proved injurious to the concrete blocks at the south breakwater in other ways besides softening them. Within a year or two after the completion of the structure, some of them were observed to be chipped on the face by the vertical cleavage of a triangular section off a corner, or of the whole face to a depth of about a foot. It was evident that there was some strain on the blocks in the plane of cleavage, but it was not understood why the giving way should be deferred for several years, and fresh cases occur every year. The unequal swelling of the blocks, from varying degrees of deterioration by the chemical action of sea-water is sufficient to account for this result. The swelling being greater near the sea face of a block, or greater in one block than in those adjacent, brings a greater pressure to bear on the part which yields to cleavage. That the face of a concrete wall tends to swell more rapidly than the interior, is seen on the roadway of the breakwater, which was built with a convex camber, but has now become slightly concave in cross section along its whole length. Cracks in the upper portions of homolithic concrete structures are due also to the swelling of the portion under water by the chemical action of sea-water on the Portland cement. They have generally been ascribed to changes of temperature, or to unequal subsidence of foundations; but the swelling of the lower part of the structure is, as a rule, the only possible cause of the unsightly cracks which open up in the lines of least resistance. Thus the defects observed in concrete structures, and the chief cause of their destruction arise from the chemical action of sea-water, and the sudden compression of air within the interstices. The same remedy applies to both evils, namely, the formation of an impermeable homogeneous mass.

It is hardly possible to compare the durability of one description of masonry or concrete work, exposed to the action of the sea, with that of another under a different exposure. The concrete bag

work forming the north pier extension is only exposed to seas striking the point of the pier, and running along its two sides at nearly equal heights, so that very little difference of pressure is produced between them. On the other hand, the concrete blocks of the south breakwater are sometimes subjected to a head of water on the sea face of 20 feet, the seas coming nearly broadside on to the breakwater during south-easterly storms, and the waves flowing over it at low water.

Mr. Messent reports that:—

> "The blocks on the north side of the south breakwater, from which the specimens 9 and 10, Table II, were taken, furnish an illustration of the slowness of the deterioration of concrete, although of injudicious proportions, where there is no regular forced percolation. The blocks from which these specimens were taken were made of concrete, in which the cement and sand were as one to four, or similarly proportioned as the deteriorated concrete of the graving dock walls, and were placed in their present position (about 4¾ feet above low water) about sixteen years ago. The block from which No. 9 was taken, had on its surface the original hard skin that usually forms on the surface of concrete built on land and afterwards exposed to air. This skin was absent from No. 10. The magnesia found in the cement is shown to be 3·32 per cent. in No. 9, and 5·49 per cent. in No. 10. The original cement probably contained about 1 per cent. of magnesia, so the addition amounts to 2·32 per cent., and 4·49 per cent., in sixteen years."

Although an addition of 4 per cent. of magnesia to the cement is required to cause the complete softening of the concrete, the partial deterioration in hardness due to a smaller increment exposes it to great danger of destruction by other forces. A slight expansion by chemical action may cause cleavage; this opens up the concrete to the reception of more water, which dissolves and removes cement, besides depositing more magnesia; and the partial softening renders it liable to rupture by compressed air, or to wear by attrition. While it is a simple matter to prevent the deterioration of Portland cement concrete in this way, by constructing all new work so as to be impermeable to sea-water, and the additional cost of so doing would be rapidly counterbalanced by the diminished cost of maintenance; the stoppage of this action on existing sea works, and its prevention in the permeable concretes, of which many of them have been constructed, is more difficult. The formation of an impermeable skin, by facing the old concrete work with strong mortar or masonry, is the plan adopted at Aberdeen; and the work done has proved more durable than the original structure. The chief difficulty consists in securing the permanent adhesion of the old work and the new. The precautions taken are, the use under water of Roman cement exclusively; the

clearing away of all decayed concrete, and of sufficient sound concrete to leave room for a thick patch; washing the surface of the old concrete, where it is above water, with a strong solution of caustic soda; and fixing iron ties between the old and new work. It is found advantageous to make the new masonry or concrete liner sufficiently heavy to stand by itself independently of adhesion to the old work. The great source of danger to these patches lies in the sea-water continuing to obtain access, through some other place, to the old work at the back of them, when the continued deterioration and swelling of the old concrete severs the connection with the new face, which it bulges and cracks.

The expenditure on maintenance of the south breakwater, refacing the surface with granite chips in Roman cement under water, and with granite ashlar in Portland cement above water, grouting and building up cavities, and depositing an apron, has amounted, since its completion in 1873, to £11,000. The cost of refacing the wing walls and entrance works of the graving dock with granite ashlar in Portland cement mortar, and depositing an apron, including a temporary cofferdam, amounted to £5,000.

The Paper is accompanied by three tracings in illustration, from two of which the Figs. in the text have been produced.

APPENDIXES.

APPENDIX I.

Analysis of Original Dry Cement.[1]

Alumina and oxide of iron	13·10
Silica	20·92
Carbonate of lime	8·18
Hydrate of lime	11·26
Caustic lime	45·39
Magnesia	0·33
Sulphuric acid	0·82
	100·00

Analysis of Samples of Decomposed Cements.

Constituents.	No. 1a.—Taken from corner of Wing Wall on South Side of Entrance, built dry inside of Cofferdam—Plaster.	No. 1b.—Taken from corner of Wing Wall on South Side of Entrance, built dry inside of Cofferdam—back of plaster skin.	No. 2a.—Taken from Entrance Wall above Culverts inside Dock.	No. 2b.—Taken from Entrance Wall above Culverts inside Dock. Drippings.	No. 3.—Taken from Outlet Culvert.
Alumina and oxide of iron	26·76	28·42	1·05	1·53	5·60
Silica	18·04	19·55	1·33	1·31	10·87
Carbonate of lime	6·61	15·78	45·72	35·42	38·37
Hydrate of lime	30·54	16·94	27·85	17·17	19·21
Hydrate of magnesia	13·57	15·08	21·03	39·96	22·30
Sulphuric acid	2·98	4·23	1·31	0·90	0·85
Soluble in water	1·50	..	1·71	3·71	2·80
	100·00	100·00	100·00	100·00	100·00

A sample of decomposed concrete taken from a block on the west side of the south breakwater was analyzed by Professor Brazier, in order to compare it with the disintegrations at the graving dock, with the following results:—

Alumina and oxide of iron	21·60
Silica	17·81
Carbonate of lime	33·08
Carbonate of magnesia	12·68
Hydrate of magnesia	9·94
Sulphuric acid	4·89
	100·00

[1] In a letter dated 24th Feb., 1892, Mr. Smith explained that, instead of "original dry cement," the heading should have been "original cement of test briquette," the original cement having been all used up before an analysis was considered expedient.—Sec. Inst. C.E.

APPENDIX II.

Results of Digesting Portland Cement in various Solutions.

The cement employed was obtained by breaking down a briquette, sifting out and rejecting the fine powder, and reserving pieces about the size of large-grained shot. Two hundred grains of the cement were taken for each experiment, and after being tied in a small muslin bag were suspended in 20 ozs. (one imperial pint) of the undermentioned fluids:—

1. Distilled water. 2. Solution containing 31 grains of chloride of magnesium per imperial pint (equivalent to 13·05 grains of magnesia, being the average proportion of this salt in sea-water). 3. Solution of 62 grains of chloride of magnesium per imperial pint (equivalent to 26·10 grains of magnesia) being double the strength of the former solution. 4. Solution of sulphate of magnesia, containing the same equivalent of magnesia as solution No. 2. 5. Solution of sulphate of magnesia, containing the same equivalency of magnesia as solution No. 3. 6. Sea-water—specific gravity 1·026, containing magnesium salts (chloride and sulphate) equivalent to 18·37 grains of magnesia per imperial pint. 7. Sea-water—duplicate of above. 8. Solution of chloride of sodium—250 grains per imperial pint.

The whole of these digestions were started at various times between the 13th and 20th of July, and remained until the 14th of October, when the solutions were disturbed for the purpose of examination.

No. 1, *Distilled Water*.—On removing the muslin bag in which the cement had been suspended, it was found to be very much incrusted on the outside; and a considerable deposit of a white material had formed at the bottom of the jar. On opening the muslin bag, the cement itself appeared quite firm, and no incrustation was visible on its surface. The incrustation on the outside of the muslin bag, and the material at the bottom of the jar proved to be carbonate of lime. The solution was found to contain 0·75 grain of lime per pint.

No. 2, *Chloride of Magnesium Solution* (*No.* 1).—The fluid contained a considerable amount both of suspended and deposited matter, which resembled in appearance what has been termed in a former report a "creamy white substance," and was found to be a mixture of hydrate of magnesia and carbonate of lime. On opening the muslin bag in which the cement had been suspended, a still larger quantity of the same insoluble material was found. The clear fluid contained 14·62 grains per pint of lime, and 0·07 grain per pint of magnesia, thus showing that nearly all the magnesia had been removed by the process.

No. 3, *Chloride of Magnesium Solution* (*No.* 2).—The appearances in this instance were very similar to those described in the above experiment, except that they were more marked. The clear fluid was found to contain 26·04 grains per pint of lime, and of magnesia 2·06 grains per pint, showing that in this case, although the solution of the magnesium salt was much stronger, nearly all of the magnesia had been removed.

No. 4, *Sulphate of Magnesium Solution* (*No.* 1).—In this case considerable action had evidently occurred. The solution was turbid, and there was a large deposit at the bottom of the jar, which was proved to contain carbonate and sulphate of lime, along with hydrate of magnesia. Both upon the outside and inside of the muslin bag in which the cement had been suspended, the incrustation had a somewhat crystalline appearance, evidently owing to the presence of sulphate of lime (gypsum). The clear fluid contained 9·10 grains per pint of lime, and of magnesia 0·10 grain per pint.

No. 5, *Sulphate of Magnesium Solution* (*No.* 2).—In this instance again the appearance of chemical action was similar to that described in the last experiment, excepting that with the stronger solution the appearance was more marked. The clear fluid contained 5·40 grains of lime per pint, and of magnesia 4·55 grains per pint. The proportion of magnesia in solutions No. 2 and No. 4 was the same, and also in solutions No. 3 and No. 5; and by a comparison of the first experiment in each case, that is to say of Nos. 2 and 4, the chemical action seems as rapid in the one instance as in the other. With chloride of magnesium, all the magnesia is removed except 0·07 grain per pint; with sulphate of magnesium, all the magnesia is removed excepting 0·1 grain per pint.

Nos. 6 *and* 7, *Sea-water.*—In each case there was evidence of considerable action having taken place. On opening the muslin bags in which the granules of cement had been suspended, abundance of the white creamy-looking substance was observable. The clear fluid in experiment No. 6 was found to contain a proportion of 4·21 grains of magnesia per pint, thus showing a precipitation of 14·16 grains from the original sea-water. The clear fluid in experiment No. 7 contained equivalent to 3·65 grains of magnesia per pint, thus showing that 14·72 grains had been precipitated from the original pint of sea-water. The results of these two experiments are strongly confirmatory of those obtained in the experiment detailed in my report of June 9, 1887.

No. 8, *Chloride of Sodium.*—This experiment agreed closely with the results obtained in experiment No. 1 (distilled water)—a proportion of lime amounting to 1·60 grain per pint seems to have been dissolved.

An additional experiment was also arranged, in which two pieces of solid cement (from a briquette), weighing together 2,400 grains, were suspended in 2 pints of sea-water of similar character to that mentioned in experiments Nos. 6 and 7, and the whole was allowed to remain at rest for the same period as the other digestions. At the end of the time there was no very marked appearance, except that here and there a few white spots were discernible. The sea-water originally contained a proportion of 18·37 grains per pint of magnesia; and after the digestion, 15·73 grains per pint, thus showing a loss of 2·64 grains per pint during the experiment.

APPENDIX III.

Extract from Mr. Pattinson's Report of Oct. 25th, 1887, giving his Conclusions from the Results of his Analyses.

On comparing the analyses of the concrete used in the work with those of the original briquettes, Nos. 1, 2, and 3, it is evident that very considerable changes have occurred in the composition of the cement used in the concrete. First—much of the lime has disappeared from samples Nos. 6, 6B, 7, 8, 10, and 11. Second—a great increase of the magnesia has taken place in the same samples. Third—an increase in the amount of sulphuric acid has taken place in the same samples. This sulphuric acid exists as hydrated sulphate of lime.

These samples of concrete, which show a diminished amount of lime and increased amounts of magnesia and sulphuric acid, are just the samples which show, by their crumbling and friable nature, that the concrete has become disintegrated and deteriorated.

There can be no doubt, I think, that this deterioration is caused by the action of the sea-water with which the cement has come into contact. According to Thorpe and Morton's analysis (Chem. Soc. Journal, xxiv. 506), 1,000 grains of

sea-water contain 3·151 grains of chloride of magnesium, and 2·066 grains of sulphate of magnesia. The magnesia of both these salts in solution is precipitated as hydrate of magnesia on coming into contact with lime, with the simultaneous formation of soluble chloride of calcium and partially soluble sulphate of lime. This chemical action of sea-water has evidently taken place in the cement used in the samples of concrete marked Nos. 6, 6B, 7, 8, 10, and 11, and notably in No. 6 sample, from which about two-thirds of the lime has been removed, and in which about twenty times the original quantity of magnesia, and more than three times the original quantity of sulphate of lime, have been deposited, thereby causing the friable and disintegrated condition which marked this sample. The same result in a lesser degree is observable in the other samples.[1]

APPENDIX IV.

TABLE OF FILTRATION OF SEA-WATER THROUGH PORTLAND CEMENT CONCRETE BLOCKS, 28 DAYS OLD, UNDER 24 FEET HEAD.

—	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Proportion . .	1 : 1 : 4	1 : 4 : 1	1 : 2 : 3	1 : 1½ : 4½	7 Days. 1 : 3 : 4	1 : 1⅔ : 5⅓
Time from putting on pressure to appearance of water through block	9 hours.	35 minutes.	13 hours, 50 minutes.	3 hours, 15 minutes.	5 minutes.	35 minutes.
	Ounces.	Ounces.	Ounces.	Ounces.	Ounces.	Ounces.
1st Day . . .	6	282	25½	46½	719½	385
2nd „ . . .	6	210½	21	41	386½	200
3rd „ . . .	2½	126	18	30	258	125
4th „ . . .	..	..	14¾	22	184½	76
5th „ . . .	..	..	..	..	137	53½
6th „ . . .	..	..	..	..	103	41½
7th „ . . .	..	..	..	..	83	24
8th „ . . .	..	..	..	..	70	23½
9th „ . . .	..	..	..	..	..	24½
10th „ . . .	..	..	..	..	Unreliable, being kept only 7 days — when taken out was found to be swelled and decomposed.	frost. 15
11th „ . . .	..	..	..	..		12½
12th „ . . .	..	..	..	..		21
13th „ . . .	..	..	..	..		12
14th „ . . .	..	..	..	..		10
15th „ . . .	..	..	..	..		10

[1] Published as Appendix II of Mr. Messent's Report on the Aberdeen Graving Dock, November 24th, 1887.

TABLE OF FILTRATION OF SEA-WATER THROUGH PORTLAND CEMENT CONCRETE BLOCKS, 3 MONTHS OLD, UNDER 24 FEET HEAD.

—	No. 7.	No. 8.	No. 9.	No. 10.	Apron Blocks for Works.	
					No. 11.	No. 12.
Proportion . .	1 : 1 : 4	1 : 4 : 1	1 : 2 : 3	1 : $1\frac{1}{2}$: $4\frac{1}{2}$	1 to 5	1 to 5
Time from putting on pressure to appearance of water through block	5 minutes.	1 hour, 15 minutes.	64 hours, 30 minutes.	13 hours, 30 minutes.	20 minutes.	5 minutes.
1st Day . . .	$5\frac{1}{2}$ oz.	44 ozs.	1 oz.	$\frac{1}{8}$ oz.	20 ozs.	$1\frac{3}{4}$ oz.
2nd ,, . . .	9 ,,	32 ,,	$1\frac{1}{4}$,,	..	$3\frac{1}{2}$,,	1 ,,
3rd ,, . . .	6 ,,	24 ,,	$1\frac{1}{4}$,,	..	4 ,,	$\frac{3}{4}$,,
4th ,, . . .	3 ,,	$16\frac{1}{2}$,,	1 ,,	..	3 ,,	1 ,,
5th ,, . . .	$2\frac{3}{4}$,,	12 ,,	1 ,,	..	$2\frac{3}{4}$,,	$\frac{1}{2}$,,
6th ,, . . .	1oz.nearly	6 ,,	1 ,,	..	2 ,,	$\frac{1}{2}$,,
7th ,, . . .	$\frac{1}{2}$ oz.	5 ,,	$\frac{3}{4}$,,	..	2 ,,	$\frac{1}{2}$,,
8th ,, . . .	$\frac{1}{2}$,,	4 ,,	$\frac{1}{2}$,,	..	2 ,,	$\frac{1}{2}$,,
9th ,, . . .	$1\frac{1}{2}$,,	3 ,,	$\frac{1}{4}$,,	..	$1\frac{1}{2}$,,	few drops
10th ,, . . .	1 ,,	$2\frac{1}{2}$,,	$\frac{1}{2}$,,	..	$1\frac{1}{2}$,,	..
11th ,, . . .	1 ,,	1 ,,	$\frac{1}{8}$,,	..	$1\frac{1}{2}$,,	$\frac{1}{2}$ oz.
12th ,, . . .	$\frac{3}{4}$,,	1 nearly	$\frac{1}{8}$,,	..	$1\frac{1}{4}$,,	$\frac{1}{2}$,,
13th ,, . . .	$\frac{3}{4}$,,	$\frac{1}{4}$ oz.	few drops	..	$1\frac{1}{4}$,,	$\frac{1}{4}$,,
14th ,, . . .	$\frac{3}{4}$,,	1 ,,	$\frac{1}{8}$ oz.	..	$\frac{1}{4}$,,	few drops
15th ,, . . .	few drops	$\frac{3}{4}$,,	$\frac{1}{4}$,,	..	$\frac{1}{4}$,,	$\frac{1}{8}$ oz.
16th ,, . . .	$\frac{1}{8}$ oz.	$\frac{1}{2}$,,	few drops	..	$\frac{1}{2}$,,	$\frac{1}{8}$,,
17th ,, . . .	$\frac{1}{2}$,,	$\frac{1}{4}$,,	damp	..	$\frac{1}{4}$,,	$\frac{1}{8}$,,
18th ,, . . .	..	$\frac{1}{8}$,,	..	..	$\frac{1}{4}$,,	$\frac{1}{8}$,,

Table of Filtration of Sea-Water through Roman Cement Concrete Blocks, One Month Old, under 24 Feet Head.

—	No. 13.	No. 14.	No. 15.
Proportion . .	1 : 1 : 4	1 : 2 : 3	1 : 2 : 3
Time from putting on pressure to appearance of water through blocks	1 hour, 5 minutes.	Block did not become hard enough to come out of mould.	Moulded and hardened, but not tried under pressure.
1st Day . .	223 oz.		
2nd „ . .	201 „		
3rd „ . .	189 „		
4th „ . .	173 „		
5th „ . .	173 „		

The cement used for the first six experiments was not finely ground, leaving 10 per cent. on a 2,500-mesh sieve; the cement for the experiments, numbered 7 to 12 inclusive, was ground to a fineness of 2½ per cent. residue on a 5,800-mesh sieve. The Roman cement referred to in experiments 13 to 15 was very coarse, leaving 26 per cent. residue on a 2,500-mesh sieve.

APPENDIX V.

Sand and Stones used for Concrete Work at Aberdeen.

Sand.—The sand used for the concrete works at Aberdeen Harbour is clean, sharp, quartzose sand, screened through a sieve of 40 meshes to the inch, and contains a small proportion of minute water-worn pebbles. It has no sea-shells, clay, or impurities considered detrimental to concrete. From experiments made with it on the shrinkage of hydraulic mortars, it appears that the shrinkage is wholly due to the fluxing and packing of the sand; that the cement brings no new element for filling interstitial spaces in the mass of sand, but is all used in coating the grains and filling in the extra space between the grains of sand due to this coating. The sand has thus the variety of size of grain requisite for the formation of impermeable mortar on the addition of a sufficient proportion of cement. A similar quality of sand is collected from the beach of the Bay of Nigg on the south side of the harbour. That forming the beach to the north of the harbour, extending a distance of 15 miles, is considered too fine for concrete work; it consists of flat micaceous grains, so fine as to be blown by a light breeze when dry, but when fluxed in water is much heavier than the large-grained quartzose sand, the specific gravity of which when wetted is as 1·5 to 2.

Similar sand, dredged from the channel at the harbour entrance, contains a proportion of sea-shells and has a specific gravity of 1·75.

Stones.—The nature and size of the stones used for the formation of concrete has a considerable influence upon its ultimate strength. Smooth, water-worn pebbles are used at Aberdeen, also road-metal of broken granite, trap, or whinstone, and granite chips. The strongest concrete is that made with granite chips or broken granite, and the weakest that made with water-worn pebbles of quartzite or whinstone. Concrete carefully made of granite chips and mortar has twice the strength of concrete similarly proportioned made with water-worn pebbles. The Author observed that concrete made with sandstone at Nairn was more tenacious than similarly proportioned concrete of granite chips, a homogeneous wall being obtained with a poorer mortar than could be used in building with granite. The most advantageous quality to be sought for in the stones next to durability, is that they should form a good base for the crystallization of the cement, a quality which may be easily ascertained by experiment.

Brick forms an exceedingly good base for crystallization; and broken brick is a favourite material with concrete builders. It is, however, very unsuitable for work exposed to sea-water, disintegration setting in from chemical action much more rapidly in contact with brick than with stone.

Discussion.

Mr. Hayter. Mr. HARRISON HAYTER, Vice-President, remarked that in a discussion five years ago on "Concrete as applied to the Construction of Harbours," he drew attention to failures of concrete made with Portland cement.[1] Mr. Bamber was led, he believed, by those failures, and by conferences with himself, to undertake the investigations he had recorded. Mr. Bamber, in his Paper, dealt chiefly with three questions: (1) the specific gravity of Portland cement; (2) the ingredients of Portland cement; and (3) the quantity of water that should be used in Portland cement mixtures. The primitive method of taking the weight per bushel might give results, from the same heap, varying as much as 2 per cent. Mr. Bamber stated "that a properly clinkered and ground cement, when new, will have a specific gravity of 3·1 to 3·15;" and, with this knowledge, it was open to any one to adopt this more scientific test of weight, which was also advocated by Mr. Carey. As regarded the ingredients, he had always advocated analysis; but this had been hitherto precluded by uncertainty about the proper constituent parts, and especially as to the percentage of lime. Mr. Bamber, whilst stating that 50 per cent. of lime seemed theoretically correct, said that, with the present form of kilns, a better cement was obtained, having 61 to 62 per cent. of lime, which was unsatisfactory, as there was danger in an excess of lime. Engineers had demanded excessive tests at the outset; and the manufacturers had consequently to over-lime the cement, whilst protesting against such high tests too soon after manufacture. One of the consequences of an excess of lime was that it might not be all taken up by the silica and alumina; and the free lime in a concrete mixture would rise to the surface and form a "slurry"; and if this was not effectually removed, which was difficult to ensure, the next layer would not unite with the lower one; and there was also the waste of so much of the cement. Again, after a while free lime would absorb carbonic acid from sea-water if the work was in the sea, or from the atmosphere if on land, forming a carbonate of lime which might be injurious to the work. The effect was more specially seen in pavings, which were often cracked all over from this cause, he believed. But the most mischievous

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 162.

source of failure was due to other causes. He had already alluded to a failure that had taken place at Maryport. Since then there had been the failure at Aberdeen, which Mr. Smith had so graphically described, and its causes. Quite recently his partner and himself were called upon to report on a precisely similar failure at a graving dock in Belfast. Whenever a wall of porous, or weak Portland cement concrete was exposed to the influence of sea-water, magnesia, in some form, was precipitated at each rise of the tide, taking away, in an altered form, the lime from the Portland cement of the concrete. He had seen concrete where in places little had been left but the gravel and sand. A creamy substance was formed in the concrete, which he had had analyzed, and was found to contain 80 per cent. of magnesium hydrate, consisting of about two-thirds magnesia and one-third water. Magnesia had a great affinity for water; and Mr. Bamber told him that two parts of magnesia would take up and solidify one part of water. The concrete expanded, lifted the wall, and broke. Thus at Maryport, a wall, 35 feet high, had lifted about $2\frac{1}{2}$ inches; and a mass of concrete in the floor of a passage, 16 feet thick, had lifted from $\frac{1}{2}$ inch to $1\frac{1}{4}$ inch. Mr. Smith had recorded a similar state of things at Aberdeen, and the like occurred at Belfast. It was some time before the deterioration and consequent results were manifested. When the work was finished, and known to be well done, as far as this could be ensured by care and supervision, after a year, or even more, the facework showed cracks and indications of weakness. The cracks might at first be attributed to settlement, or to variations in temperature; for, in a long concrete wall, without special provision for expansion and contraction, hair cracks would generally be found on the face, scarcely visible in summer, but sufficiently wide in winter to admit a thin sheet of paper. The cracks might be stopped up, but in a short time the evil would spread until the injury became manifest. Fortunately the cause had now been discovered to the satisfaction of those engineers who had had practical experience in the matter. It was also fortunate that the injury could in future be prevented by keeping the sea-water from the concrete wall by founding it on an impervious material where practicable, and by isolating it by clay backing or an asphalte coating, or by rendering the exposed surfaces with stronger and finer cement concrete or mortar. With regard to the quantity of water that should be used in Portland cement mixtures, the common practice had been, as seen continually in specifications, to use as little water as possible; but Mr. Bamber rightly urged the use of as much as the mixture Mr. Hayter.

Mr. Hayter. would readily take up, otherwise the constituent parts could not be thoroughly incorporated and chemically combined; and the slurry, above referred to, would be more liable to be formed, and the concrete would be porous. In conjunction with his partner, he had recently been using about 50,000 tons of cement yearly, all manufactured in this country, and examined and tested under the supervision of his firm. As regarded grinding, the practice only a few years ago was to grind so that the bulk would pass through a sieve of 900 meshes per square inch; then this was raised to 1,600, and then to 2,500 meshes per square inch. Some engineers, indeed, insisted upon 3,600, and even went so far as 4,900 meshes per square inch. His practice was to adopt a sieve with 2,500 meshes per square inch; and he had tried unsuccessfully to arrange for 95 per cent. to pass through, but now provided for $92\frac{1}{2}$ per cent. to pass, which manufacturers were ready to accept. Such a cement was very fine indeed; it set as hard as the stones or bricks it united; and it was questionable whether the cost of finer grinding would confer a corresponding benefit. He would be quite willing to accept the specific gravity mentioned by Mr. Bamber and Mr. Carey, as applicable to existing conditions of manufacture; but if the percentage of lime was reduced, some modification might be necessary. He specified that the usual test block of $2\frac{1}{4}$ square inches section should stand 300 lbs. after forty-eight hours, 450 lbs. after four days, and 700 lbs. after seven days. If it was much in excess, the cement might contain too much lime, in which case it would not be so strong after a year or so. The lime should not exceed 60 per cent., and if it could be reduced to 55 per cent., it would be better; and he thought that engineers and manufacturers should aim at this. The quantity of silica and alumina would depend upon the quantity of lime; and he should look with suspicion upon a cement with more than 1 per cent. of magnesia. He had heard of analyses giving as much as 4 or 5 per cent. of magnesia. Sometimes Portland cement was urgently needed to meet an emergency, or it might have to be used in localities where there was no chemist, or no mechanical appliances at hand. The best course then was to make small cakes, 5 or 6 inches square and $\frac{3}{4}$ inch thick, and place them in water; and if, after twenty-four hours, they did not show any signs of cracking or softness on the surface, and if they were made hot and then wetted and did not "give," in all probability the cement could be used safely. Such a cement might not be the best kind, which could only be determined by the more elaborate tests, but it would not crack or fly. The hot-water test recently

tried, and needing further development, might come into more common use, as it could always be applied; and it was a good test of excessive lime. In experiments made by Mr. Deval,[1] Portland cement was mixed with water heated to 176°; and, if the cement contained above 64 per cent. of lime, it would not harden. The West Kent Portland Cement Company told him that they had tested cement by mixing it with boiling water with the same result; and it was more satisfactory to use boiling water, inasmuch as a fixed temperature could be maintained, a difficult matter below the boiling point. He supposed that the excess of lime was not taken up by the silica and alumina, that it became slaked, and broke up the mixture. The supervision of the manufacture of Portland cement advocated by Mr. Carey, certainly if carried to any extent, appeared to him questionable, inasmuch as engineers could not form so good a judgment even of the raw material, or be so well acquainted with the processes of manufacture, as the makers themselves. Such control would relieve the manufacturers from responsibility, both as to the manufacture and the results. The engineer's province, in his opinion, was to see that the cement was satisfactory after manufacture and before acceptance, and his inspection should be confined to this. Mr. Hayter.

Mr. E. Leader Williams said that he agreed with many points which Mr. Hayter had laid down. On the Manchester Ship Canal, 176,000 tons of cement had been used since the commencement; and he expected that before it was finished they would use 200,000 tons. Their difficulty had been a practical one; for when an order of 7,000 tons per month was put upon a busy market, it was sometimes a difficult matter to get it. Mr. Abernethy and himself had felt, in making the specification for cement, that it was not desirable to put it too high. If the work had been similar to reservoir walls, against which there would be a great head of water, a very perfect cement would have been needed; but for non-tidal dock walls, only 36 feet high, and 20 feet wide at the base, it was unnecessary to adopt such high specifications, which would considerably increase the cost of the cement, and the difficulty of getting it. Sometimes the works had been almost at a standstill for want of cement, although it was obtained from twenty-four makers. On the whole, although they had received very fair cement from the north country makers, they had as a rule found that the cement from the Medway and Gravesend districts Mr. Williams.

[1] "Bulletin de la Société d'Encouragement pour l'Industrie Nationale," August 1890.

Mr. Williams. turned out the best. Forty years ago he was on the Admiralty Pier works at Dover, when cement making was comparatively in its infancy, and they thought a good deal of using 50 tons in a day or two. At that time Major Pasley's useful book was the only authority on the subject; and the cement then obtained was not burnt so well, and the clinkering was not so perfect, mainly because it cost more in grinding; and the amount of lime was very variable. Still, no work had set better than the Admiralty Pier at Dover. They had seldom found a block fail. That was a good proof that cement, fairly well made, and well used, was a reliable article. In mixing cement on the Ship Canal works, they used mixers of various patterns, and a good deal was done by hand. Having had to cut into walls after construction, they had not found much difference in the cement concrete made by hand, or by machine; but, on the whole, the machine-made concrete was the best. He was satisfied that much concrete was used in too dry a state. He liked to see what was called the fat rising to the surface, because it showed that they might depend upon having a good concrete. The quality of the water was very important. They might have a high class cement, but if there was any appreciable amount of silt or mud in the water, the gravel, or the sand, it was simply ruined. It was astonishing how they could weaken down the cement used if they really had good gravel and sand. In the course of the works at Dover, when the Amsterdam Ship Canal Works were about to start, Sir John Hawkshaw asked the contractors, Messrs. Lee & Sons, to see how far the cement would amalgamate with the sand, because no stone could be got for the breakwater works in Holland, and it was a question of making sand blocks. He (Mr. Leader Williams) made those test blocks for Sir John Hawkshaw; and he found that, after carefully washing the sand, if it was at all dirty, or using very clean sand from the seashore, they made very fair blocks with proportions of 10 to 1, without any gravel at all. In the Ship Canal Works, in order to economise and also to improve the concrete, they used rough blocks of sandstone, which the navvies called "plums in the pudding." The great thing was to keep them well apart, so that there might be an absolute joint of cement concrete between the blocks. He could not account for the absence of hair cracks in their walls in any other way than by the use of these blocks of sandstone. They had miles of concrete walls; and although they had had difficulties to contend with, one or two cases of settlement, and a slight going forward of the walls on clay, so that they had had to put piling in front, they had not had

Mr. Williams.

the hair cracks that were seen on so many walls. He knew one case in which the engineer was so doubtful about the expansion and contraction of concrete on a long wall, that it was built in separate lengths. They had found that quite unnecessary. He entirely agreed with Mr. Hayter that cement which set quickly, and stood a very high tensile strain in a very short time, should be looked upon with suspicion. He might be old-fashioned, but he thought from his experience with lias, and other mortars, that slow-setting limes ultimaetly became the hardest; and he believed that the same rule to some extent applied to Portland cement. By all means let them pay attention to the gravel and sand; and then a fairly good cement would be sufficient for such works as dock or lock walls.

Mr. Hutchinson.

Mr. T. C. Hutchinson said that, as an iron smelter, he had some knowledge of chemistry; and he had had considerable experience of Portland cement concrete in harbour works during five years. The Skinningrove Iron Company was producing and using a cement with eminently hydraulic qualities and tensile power, with not more than 45 per cent. of lime in the finished cement. That cement was mixed with three of sand and one of cement; and in twenty-eight days (twenty-seven days being in water) the average tensile strain was from 370 to 390 lbs., with a gradually increasing strength for from six to twelve months. The tests had extended over a long period, and they ran up to over 900 lbs. per square inch in the twelve months' test. They passed their cement through a sieve of 32,000 meshes to the square inch, and the average residue was from 12 to 15 per cent. The cost of grinding was very great to get it down to that degree of fineness, but the extra tensile strength was exactly in proportion to the fineness. The failure of concrete in sea-water, recorded by Mr. Smith, might be attributed altogether to the large excess of lime in the cement used. He thought it had been proved, both from experiments, and the analyses of Professor Brazier and Mr. Pattinson, that Portland cement with 60 per cent. of lime contained a large quantity of free lime. If an ordinary sample of Portland cement was treated with distilled water which had been boiled so as to drive off all the carbonic acid, and the water run through the Portland cement, upon the evaporation of the water a considerable portion of the lime would be found in the residue. If free lime was thus brought away, he thought it was evident that there was free lime in the Portland cement. Mr. Messent had recommended that Roman cement should be used instead of Portland cement in facing work; and the proportion of lime in Roman cement was

Mr. Hutchinson. very much less than in the Portland cement which had failed. His engineer, Mr. Kidd, on going to inspect the Tyne piers, asked why Mr. Messent had so strongly recommended Roman cement instead of Portland, and Mr. Messent's assistant then showed him the blocks that were put down in the Tyne thirty or forty years ago, which were perfectly sound, whilst the Portland cement blocks immediately adjoining them were more or less disintegrated. The cement they were now using at Skinningrove, having built a pier 900 feet long, about 40 feet from low-water, contained about 45 per cent. of lime. The concrete, very highly charged with water, had been deposited *in sitû* as described by Mr. Kidd;[1] and they had thus obtained a perfect mass of concrete, 900 feet long, homogeneous throughout. After five years, the wall was as perfect as when it was commenced. A piece of concrete four years old, cut from the toe of the apron, was perfectly dry, and was so strong that all the large pieces of slag put in were broken through. Two men with a steel bar and a heavy sledge-hammer took six days to cut a piece 2 feet wide by 6 feet long from the parapet of the wall. There was no instance in which any part of the stone came away and left the matrix exposed. They used the Leighton-Buzzard sands, and in breaking the briquettes in twenty-eight days, or a longer period, they found in many cases the quartz of the sand broken through.

Mr. Bevan. Mr. THOMAS BEVAN said that Mr. Carey had told them what an engineer should put in his specification for cement. He (Mr. Bevan) would suggest what he should not put. It had been pointed out by Mr. Faija that a specification of weight per bushel was useless.[2] He had known a case where a manufacturer of cement, in this country, undertook to deliver cement hundreds of miles by railway in the interior of Australia, subject, among other things, to a weight per bushel of 112 lbs., which looked reasonable; and the manufacturer shipped good cement of 112 lbs. per bushel. By the time the cement reached its destination, the cement was naturally reduced in weight to 102 lbs. per bushel, and was rejected; and was returned by railway to Brisbane, and sold with the stigma that the cement had been rejected by a Government engineer, and the large loss of transport.[3] It should be stated in the specification where and when the weight would

[1] Minutes of Proceedings Inst. C.E., vol. cv. p. 231.

[2] Society of Engineers, Transactions, 1888, p. 49.

[3] This loss of weight can be verified by spreading out a bushel of newly-ground cement in a $\frac{1}{2}$-inch layer, and weighing it again at the end of eight days. In an experiment by Mr. Faija, the loss of weight was 10 lbs.

be taken. A specification of 112 lbs. per bushel, taken at the place of manufacture, was the maximum point at which the manufacturer would not perceive a distinct invitation and compulsion to over-lime his cement. A very high tensile strain exacted at seven days could readily be obtained by chalk beyond the just proportion, and consistently with the appearance of a sound briquette then, and long afterwards; and that was another invitation to free lime. But the specification of a high weight per bushel, even if accompanied with a low tensile strain at seven days—a combination which might be met with in some specifications—came from an over-liming engineer, as it was absolutely impossible to manufacture properly out of the pure white chalk of the Thames a cement much, if at all, higher than 112 lbs. to the bushel, unaccompanied by an extraordinarily high tensile strain in seven days. Therefore, he counselled engineers not to specify more than 112 lbs. to the bushel at the place of manufacture. Secondly, a mould of $1\frac{1}{2}$ by $1\frac{1}{2}$ inch should not be taken, but a 1-inch mould; and 900 lbs. for the former was not the equivalent of 400 lbs. for the latter, because it was almost impossible to gauge a $2\frac{1}{4}$-inch briquette so advantageously as a 1-inch briquette. There was no difference between a 1,000 lb. briquette properly gauged, and one of 1,250 or 1,300 lbs., because the free lime necessary to give the former would give the latter. The same was true, within certain limits, of the 1-inch briquette. The reason why Mr. Leader Williams had no hair cracks along his walls was simply that he had a very moderate specification of 350 lbs. to the square inch, in seven days, on the 1-inch briquette; and he had not sent out any invitation for free lime. He demurred to Mr. Carey's suggestion of not less than 180 lbs. in three days; and he should propose *not more* than 200 lbs. at that period, because it was perfectly easy so to over-lime the cement that it should give just as high a tensile strain at three days as at seven. He counselled the engineer not to go into the other extreme, and specify not more than 350 lbs. in seven days, because he was quite sure that a sound cement, without any appreciable free lime in it, could be made to go, with good conditions of gauging, up to, and perhaps a little beyond, 400 lbs. in seven days. But what were good conditions of gauging? A merchant often asked a manufacturer, "What will you guarantee your cement will go to?" A prudent manufacturer always answered, "Tell me who is going to test it; I can only guarantee what it will test in my sample room." The gauging must be operated with the greatest promptitude, particularly with a quick-setting cement. He was glad

Mr. Bevan.

Mr. Bevan. to notice that Mr. Carey stated that the best cement was quick-setting, which was quite true, although it would get slower by keeping and exposure; and it would keep unimpaired in quality for many years. Quick-setting cement, standing 350 lbs. at seven days, was the strongest possible cement, and would in time run far ahead of slow-setting cement; and over-limed cement was slow setting. The reason why Mr. Leader Williams found the Thames and Medway cements superior to those of the north of England, was due to the mixed character of the chalk shipped to the north as ballast from various chalk pits, and the inferior quality of the inland clay, full of sand, and resembling London clay. In dealing with the cement for the briquette, it was well to expose it, on a piece of glass or slate, ½ inch thick, scored with a trowel, to the air, in a cool covered place, forty-eight hours at least, and sometimes seventy-two hours before gauging. With reference to the water that might be used in mixing a little briquette, the over-liming engineer used 25 per cent. of water, and often more; whereas 16 to 17 per cent. of water was ample for the strongest cement, and more water often led to apparent failure of tensile strength. A fracture-curve of briquettes gauged with different percentages of water, carried out for Knight, Bevan, and Sturge, by Mr. Faija, upon the same sample of their average cement, showed that with 25 per cent. of water, the tensile strain was, in seven days, 195 lbs. per square inch; with 23 per cent. of water, 252 lbs.; 21 per cent., 308 lbs.; 20 per cent., 353 lbs.; 19 per cent., 373 lbs.; 18 per cent., 425 lbs.; and with 16·67 per cent., 432 lbs. The cement was gauged with Mr. Faija's gauger; and he disagreed wholly with Mr. Carey in his preference for hand-gauging, which was a question of flexibility of wrists and practice; while the danger of lingering over, and messing the cement was reduced to a minimum in the machine. If a sand test was specified, the engineer should state what sand, and, in specifying so many parts of sand, whether he intended by measure or weight, for 3 parts of sand to 1 of cement by measure represented about 3½ parts of sand to 1 of cement by weight. Also, he would advise not to specify, as was done for the Colombo Harbour Works, that the cement must weigh at least 118 lbs. per bushel in its dry uncompressed state, and that the cement should be spread to a depth not exceeding 3 feet in a dry, well-ventilated shed on the maker's premises, and entirely turned over, and turned over a second time seven days after. What was the purpose of spreading the cement, after bulking, to a depth of 3 feet, and repeatedly turning it over; if it was to get rid of the free lime, why put free lime there? If

Mr. Bevan.

the engineer's object was to obtain the cement at as low a cost as possible, that it might compare favourably with other materials, was it reasonable to suppose that the manufacturer—who, Mr. Carey said, should have about ten weeks' work in store, which might run to 30,000 tons, and which would be bulked at least 10 or 15 feet high—could thus spread and turn over, or bin it all? The manufacturer would want accommodation utterly beyond the confines of his works, and the engineers could not buy at the price of the market. He would counsel the engineer to specify that there should not be a larger residue than 10 per cent. on a 50-mesh sieve; and he thought that 7½ per cent., suggested by Mr. Hayter, was the very maximum of fineness. If extreme fine grinding was specified, the manufacturer must either double his grinding power, or be content to reduce his output by 50 per cent. A large augmentation in price must be conceded, and far more than was commensurate with any advantage gained. Mr. Carey trusted that the time would arrive when cement would be produced fit for immediate use; but it was so produced now, and there never was any difficulty in it whenever manufacturers were permitted to dispense with over-liming. He would counsel the engineer to decline Mr. Carey's invitation to go and live with the manufacturer, superintend his operations, and manage his business for him. The prudent engineer would only deal with the manufactured article. The prudent manufacturer would not believe that he could be taught how to make cement, any more than an engineer how to test it; he knew the right clinker by the colour, the handling, and by twenty instincts. He thought there was little scope for variations in chemical constitution where pure white chalk and pure clay were used, as in the manufactories on the Thames, and that little magnesia would be found in such fixed materials. If, however, much free lime existed in the cement in contact with the inexhaustible supply of magnesia in the sea, this magnesia might replace the lime, and 12 per cent. of magnesia might be found in the disintegrated mass. Engineers should draft their specifications as simply as possible, and be content with plain reasonable conditions, so that the manufacturer might be able to give them all the economy to which they were entitled. He noticed Mr. Carey's preference for Goreham's patent in the manufacture, and his conclusion, which arose from inexperience in that matter, that there were strata in the cement washings of large backs. There were no such strata. He much preferred, even at some additional expense, to be able to look at the washings of three months' material, than to have to depend upon the accuracy

Mr. Bevan. of the composition passed through a dry mill and conveyed directly on to the drying floor. The mixture must vary with the materials, or the accuracy of the weighers, when it went without pause on to the floors. The only rectification could be a mixture subsequently, in the warehouse, of good and bad cement. He believed the manufacturers who worked by Goreham's patent did always expect to mix in the warehouses after the cement was ground. Those who worked by the system of large backs never did. The reason why, as Mr. Carey stated, in laying out new works, the Goreham system was now generally adopted, was that in not one in ten of them was there space to do otherwise. Mr. Carey admitted that the weighing of the materials into the washmill in the Goreham's plan afforded little certainty, owing to the different degrees of moisture they contained, and advocated the use of a calcimeter; but no calcimeter had ever been necessary in the old and more natural process. He, moreover, disliked the little white grit, from very minute particles of caustic lime, which Mr. Carey had referred to as visible later in the clinker. He was well acquainted with the history of the Aberdeen breakwater, and in old times his firm supplied most of the cement used therein under Mr. Cay. In Mr. Cay's specification for 2,000 tons, supplied between 1869 and 1870, the tensile strain at seven days was 450 lbs. on $2\frac{1}{4}$ square inches. Towards the end of 1870, Mr. Cay altered it to 600 lbs. In 1872 and 1873, it was 600 lbs., and in 1877, 675 lbs. It was always tested very severely, and unfavourably for the briquette; and there was always a difference of about 200 lbs. at least between their sample-room tests and Mr. Cay's. In 1881, Mr. Smith specified 900 lbs. to a section of $1\frac{1}{2} \times 1\frac{1}{2}$; and Mr. Faija's Paper of 1888 stated that it had been advanced to 1,000 lbs. If an engineer required 900 or 1,000 lbs., under pain of rejecting cement hundreds of miles from the manufactory, a manufacturer would have to furnish a good margin of at least 200 lbs. more. The weight per bushel, in both Mr. Cay's and Mr. Smith's specifications, was not less than 115 lbs., nor more than 124 lbs. per bushel. Did engineers believe that better cement was now made than that of thirty-eight years ago? It was a pleasant delusion. There were the same materials, the same capital, the same care. Was there anything better than the old Alderney breakwater, made at a time when manufacturers were not pressed to over-lime their cement, which would last as long as any natural stone, and which occasioned a great deal of trouble in devising how to get rid of it now that it was no longer wanted? Had any engineer anything better to show than Mr. Smith's

neighbours of Wick, where up to the present day no higher tensile strains had been asked for a seven days' test, no cement had been turned over, and no furnace invoked to drive out water from an immature briquette? Mr. Bevan.

Mr. Leedham White said he agreed with much that had fallen from Mr. Bevan, especially in regard to not using over-limed cement. With regard to magnesia, he was glad that the fact had been elucidated—a fact affirmed by every chemist who had given attention to the subject—that the deterioration of Portland cement concrete, when exposed to the action of sea-water, did not arise from the presence of magnesia originally in the cement, but from the double decomposition which resulted from contact of sea-water with the concrete. Chemists knew that magnesia and magnesian salts did comport themselves in peculiar ways from many chemical points of view. The double decomposition between the chlorides and sulphates of magnesium, and bodies containing lime, was no novelty; and to a chemist, the reason of the deterioration of the Portland cement concrete at Aberdeen would be obvious. But why had Portland cement concrete failed in that, and a few other instances only, out of the thousands of instances in which it had lasted forty years, giving most admirable results when used in sea-water. He hazarded the explanation that the concrete, in this particular case, was not properly made. Twenty years ago he was in Aberdeen, and examined one of the concrete blocks made at the beginning of that particular work. The block was pointed out to him as not giving satisfaction to the engineers; and, although it had been made several weeks, he had no difficulty in crumbling a piece off in his hands, part of which he took home and washed, which disclosed that the sand, which had been used very liberally, was so minute in the grain that, though sharp and clean, it was little better than dust. He was so impressed with the faulty character of the sand, that he took a sample of the cement to the manufacturer, and told him that he would certainly hear complaints of the cement, and ought to know how it had been treated. He did not know whether sand of that quality was subsequently used in the work, but, as a manufacturer, he affirmed that if such sand was used at the Aberdeen works during successive years, it was a miracle that the concrete had ever stood at all. Whatever might have been the cause of the failure of the concrete in that particular case, he thought that all engineers would agree that if it was due to magnesia, then it was to the magnesia in the sea-water, and not to magnesia in the cement itself. If that was accepted as proved, the tests imposed Mr. White.

Mr. White. during the last five or six years, restricting the presence of magnesia in Portland cement to from 1 to 2 per cent., were futile. Every test which could be shown to be futile, was bad from a practical point of view, because it must give trouble to all concerned, and would eventually restrict the use of cement by increasing its cost of production. With regard to the part of Mr. Carey's Paper relating to the chemical composition of Portland cement, while the old idea was that it was a triple silicate of lime, alumina, and iron, a theory had been in vogue for several years among German chemists that, though the presence of alumina or iron was absolutely necessary for the production of a good cement, the rôle played by these substances was a transitory one. The theory was that the alumina and iron locked up the silica, and prevented it combining in the kiln with more than one atom of lime, and that the rest of the lime was left for the time in a free state; that eventually, when the cement was gauged with water, the chemical action set in, and the water became a carrier, dissolving the particles of lime, and conveying them to the silica, re-dissolving, as it parted with the lime, fresh portions of lime, and conveying these to the silica. The water thus acted as carrier until the silica or lime was all combined, the excess of either remaining in a free state. That theory, if true, furnished the key to two or three difficulties. It showed why cement that was not over-limed was a good cement to use; for Portland cement did not arrive at anything like final hardness until it had been gauged at least three years; and if during that time it was growing in hardness, that proved that beneficial chemical action was still going on. Therefore, provided the right quantity of lime was used, and the cement properly burned, the theory showed that ultimately, when the lime was all combined with the silica, moderately-limed cement, which had been perfectly safe in the meantime, should necessarily arrive at the same strength as an over-limed cement, which might have shown greater strength at first at the expense of durability. When studying chemistry as a young man, he was told that cement was simply a compound of silicate of alumina and lime, and that when water was added to it, it assumed a state of amorphous crystallization, a rather ambiguous term. In ordinary crystals, water remained fixed as water of crystallization. In the case of Keene's cement, or Parian cement—not really cements, but indurated plasters—the water put into them remained there. Keene's cement, if heated red-hot, would lose 20 per cent. of water. In Portland cement which was some years old, the proportion of water fixed in the cement was

infinitely less, the water having served a temporary purpose only. When it had brought the lime in contact with the silica, it left the cement so soon as the last atom of silica had combined with the last atom of lime. Some chemists held that the alumina and iron had then done their work, and remained in the cement and concrete as an inert mass. A great deal of stress had been laid by the Authors and speakers on the necessity of using sufficient, though not an excessive amount of water in gauging Portland cement. It was equally important to keep the water there until it had done its duty. Twenty years ago, in hot summer weather at Washington, he was shown a large expanse of floor, made with good cement, which had utterly failed. On investigation he found that the work had neither been shielded at all from the hot sun, nor sprinkled with water during the process of setting, though the temperature was about 100° in the shade. Consequently the water, which ought to have stayed in the cement for months, had mostly evaporated in a few hours; so that no wonder the floor was rotten, and the cement work pronounced imperfect. As a manufacturer, he wished, in conclusion, to offer a tribute to the great ability exhibited in the Papers, even though they might venture to differ from one or two of the points contained in them. Mr. White.

Sir Douglas Fox.

Sir DOUGLAS FOX said that, from many of the good makers of the Thames and Medway districts, to which his experience was chiefly confined, the engineer could receive, without any difficulty, a thoroughly good cement, sufficiently strong and reliable for all practical purposes. He found it unnecessary, for ordinary work, to put any special clause into the specification, beyond a weight of 112 lbs. per bushel, and the very moderate breaking strain of 750 lbs. for $1\frac{1}{2}$ by $1\frac{1}{2}$-inch briquettes after seven days. He had, however, found it necessary to carry on a regular system of inspection, which showed that, from the best manufacturers, they obtained cement of very fine and equable quality. Mr. Hayter and Mr. Leader Williams referred especially to the use of cement in very thick walls. He (Sir Douglas Fox) could bear testimony to its successful use in large quantities in comparatively thin walls, under rather special and difficult circumstances, in tunnel and other work exposed to great hydrostatic pressure. Where used in walls or inverts of that kind, he found it very important not to use very smooth bricks. He had had cases of failure where very smooth blue Staffordshire bricks had been used. The brindle brick, whilst cheaper, was more effective where hydrostatic pressure tended to lift the invert or to move the wall. A careful mixing of the cement was too much neglected; and it was very

Sir Douglas Fox. important to use plenty of water, which made the result much more equable. Throwing cement from a great height was very liable to separate the cement from the other constituents, and a much more homogeneous mass was obtained from treading in. He had seen several cases of serious failure in concrete caused by excess of lime; in one case a wall of very great size, which, as far as strength to resist pressure was concerned, could not have been better, was honeycombed throughout, owing to unequal shrinkage of the concrete, caused, he believed, by the presence of too much lime. Another cause of failure was filling the pockets of a comparatively thin surrounding wall with concrete in cement, a process which required special care. In one instance, both the abutments and piers were seriously damaged, and some portions absolutely crippled by the swelling of the concrete, which had been placed in the pockets, the expansion being manifested by the rounding of the top. It was, therefore, most important to fill pockets gradually in thin layers, and to tread the work carefully in wherever possible, whereby any danger would be avoided. He believed they had in Portland cement, if manufactured by those who understood the business, and especially if it had been kept a fair time before it was used, a material upon which engineers might rely to bear the test of years.

Mr. Law. Mr. Henry Law said that the very few cases of failure where concrete had been used in sea-water, and the very large number of cases where it had been perfectly successful, showed that there must have been some very abnormal circumstances which led to the failure in those particular instances. Mr. Williams had referred to the blocks which had been made for Dover Harbour. It devolved upon him (Mr. Law) to use about a thousand of those blocks (7 feet by 4⅗ feet by 3 feet) in a sea-wall at Margate. They were made with 1 of cement and 8 of gravel, and had been under water for about three years before he had to use them, and were then so perfectly homogeneous and solid, that in cutting some of them for closures, the gravel stones split, and did not come out of their matrix. The wall was built in steps, and pockets of plastic concrete were put in the spaces between the stones forming the inside and outside casing of the walls. The sea came over the work at every tide, and as it rose to the successive steps, a thin film of Medina cement was spread over the pockets, and also run down the outside of the joints to protect them; and although the work was done in very rough winter weather, there was no failure, and no symptom subsequently of swelling. One great cause of failure was putting concrete into

walls too dry, for the moisture being abstracted from it by contact with drier material, the cement became pulverulent and did not set properly, and the water finding its way into it dissolved the lime. At the Thames Tunnel, the gray stock bricks were soaked for twenty-four hours before use, and when arches were cut through the central wall, it was difficult to determine, even with a glass, exactly where the brick ended and the cement commenced. He noticed a strange divergence between the quantity of water which the Authors of the first two Papers considered would give the best results. Mr. Bamber said there should be 40 lbs. of water for each cubic foot of cement; and in the blocks which stood well, there were $31\frac{1}{3}$ lbs. to the cubic foot; in those which were partially attacked there were $23\frac{1}{2}$ lbs.; and in those which were completely disintegrated, $15\frac{2}{3}$ lbs. But Mr. Carey said that he got the best results by using 220 lbs. to the cubic yard, not of concrete but of material. Allowing 20 per cent. for the shrinkage of those materials, that would amount to a little over 10 lbs. to the cubic foot. This was a very important subject, because he believed that in the distant future concrete and aluminium would be the materials chiefly used by the engineer. Mr. Law.

Mr. E. W. Young said that about seven years ago the Government of New South Wales founded an establishment on Cockatoo Island for testing cement used in their own works, and where importers of cement were allowed to send it to be tested, and certificates were issued as to the quality. As officer in charge of the works, those certificates passed through his hands; and he had prepared Tables, showing some of the results. Table I showed the abstract of all the cements. The lowness of the specific Mr. Young.

Abstract of Portland Cement Tests.

I.—Briquettes one Square Inch in Section, of 3 *to* 1 *Composition.*

No.	Specific Gravity.	7 Days.	28 Days.	3 Months.	6 Months.	12 Months	Remarks.
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
1	3·075	173	247	340	395	433	Mean of samples tested.
2	3·03	151	211	281	314	327	„ ten weakest samples.
3	3·086	231	322	421	482	521	„ ten strongest samples.
4	3·15	363	435	485	536	569	Maxima attained under each column.
5	2·63	78	134	161	191	257	Minima ditto.
6	3·10	146	208	282	315	346	Mean of twenty-two consecutive samples; nineteen tested up to 6 months, and only ten to 12 months.

Mr. Young.

II.—Fine v. Coarse Grinding, and Slow v. Quick Setting.

No.	Specific Gravity.	Residue on sieve of 14,400 Meshes per Sq. Inch.	Time of Setting.		7 Days.	28 Days.	3 Months.	6 Months.	12 Months.	Remarks.
		Per cent.	H.	M.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
1	3·01	16·81	..		166	262	348	416	434	Residue under 20 per cent., mean.
2	3·06	42·60	..		168	222	337	394	421	Residue over 40 per cent., mean.
3	3·09	29·20	0	22	142	236	319	366	416	Setting in 35 minutes or less, mean.
4	3·04	22·40	7	30	143	220	325	402	452	Do. 7 hours or more, mean.
5	3·086	27·64	3	56	..	..	..	..	..	Ten strongest cements, mean.
6	3·03	29·70	2	53	..	..	..	..	..	Ten weakest cements, mean.
7	3·10	..	1	42	..	..	..	..	..	Twenty-two consecutive samples.

III.—Comparative Strength of Various Sands.

	Standard Sand.			Harbour Sand.			
No.	7 Days.	28 Days.	3 Months.	7 Days.	28 Days.	3 Months.	Remarks.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
1	165	224	392	119	171	307	Mean of numerous tests.
2	126	182	..	102	121	..	Harbour sands screened through a coarse sieve to get rid of shell, and caught on a fine sieve to get rid of finer grains.
3	39	31	28	..	..	..	Percentage of strength in favour of standard sands.
				Crushed sandstone, dirty and unwashed.			
4	136	215	..	114	191	..	Mean of several tests.
5	19	125	..	..	..	..	Percentage in favour of washed sand.
6	..	255	..	..	303	..	Two consecutive tests giving anomalous results, due probably to use of damp washed sand.
7	..	264	..	..	322	..	
8	186	..	..	..	..	..	Sand damped 12 hours before use, 1½ ounce of water being added when gauged.
9	210	..	..	..	..	..	Sand used dry, 2 ounces of water added when gauged.

gravity was probably due to the effect of time, and the heat of the tropics, on the cements in their long voyage. The average was about 3·075, and the average of the strongest cements did not reach 3·1. One specimen only had a specific gravity as low as 2·63; but there were several of 2·97, and one of those was one of the strongest. He had given only the compo tests, because those were of most interest to engineers. The second Table showed comparative results of fine and coarse grinding. In the certificates of the cement, the amount of residue on three different sieves, the time of setting, and the temperatures were given; and all precautions, necessary to give uniform results, were taken. There was not much difference between the coarse and fine grinding; the residue was under 20 per cent. on the fine grinding on a mesh of 14,400, and in the other case it was over 40 per cent. It mattered little how the cement was made, or what was its coarseness, provided it gave good mortar. On comparing quick and slow settings, he found that the best cement took from four to five hours to set. Tests made when cement was very expensive (Table I, No. 6) gave very low results; and these cements were very quick-setting, the average time being one hour forty-two minutes. The average time of setting of the strong cements was three hours fifty-six minutes, and of the weakest cements two hours fifty-three minutes. Tests made for his own satisfaction, with regard to the qualities of sand, were shown in Table III. The standard sand, of crushed sandstone washed, was over 30 per cent. stronger than harbour sand, a clean sharp sand, rather finer in grain, the weakness of which must, he believed, be attributed to the presence of numerous small particles of shell of small cohesive strength. In a comparison between clean washed sand and dirty sand, the latter was only 12 or 13 per cent. weaker than standard sand, and considerably stronger than clean harbour sand. Therefore, dirty sand, whilst much cheaper, might be even stronger than clean sharp sand. In testing with sand damped before gauging, he got a much lower result than if the sand was used dry, due probably to the latter absorbing water after gauging. He suspected that dry clayey sand gave comparatively high results for the same reason. At Cockatoo Island, though the water oozed through the joints of the masonry, and there was a considerable efflorescence, the mortar remained quite hard. He considered that cement should not set under three hours, as it frequently happened that a skip load of mortar might not be used up for an hour or more, which, with a quick-setting cement, might be serious. Again, in forming concrete

Mr. Young.

Mr. Young. in mass, weak places might result from the disturbance of concrete partially set by the trampling in of fresh material, which would be avoided by the use of slow-setting cement. A cement giving a high test at the end of a short period, provided it did not afterwards deteriorate, was valuable because the work was liable to be subjected to its maximum strain within two or three months of its completion, as, for example, the arch of a culvert or a retaining wall. On the other hand, quick-setting cements might be valuable in special cases, such as tidal work. In concrete work it was well to be as far as possible independent of inspectors, and to be content with fairly good work.

Mr. Faija. Mr. HENRY FAIJA said that the amount of water to be used depended entirely on the quality and quantity of the aggregate. With a porous aggregate, which absorbed a great deal of water, and a large quantity of it, they required more water than when using a small quantity of non-absorbent aggregate; and to lay down as a rule the use of one-third water was a mistake, for the proportion of water used must vary according to circumstances. In Mr. Carey's specification, the specific gravity, 3·1, was too high for ordinary purposes, for not one cement in ten, unless absolutely fresh, had that specific gravity; and from a very large experience he believed that 3·07 was quite high enough. Mr. Carey's figures for tensile strength, though they might constitute a good cement, did not ensure it. The tensile strength of cement should not be defined as any particular strength at a given date, but as a minimum with a given percentage of increase between different dates. A cement was thus secured that had a growing power; whereas a cement might comply with Mr. Carey's specification as to tensile strength, and yet at seven days have a greater tensile strength than at twenty-eight days, which was indicative of a bad cement. He objected to having English and foreign measures mixed up as to fineness; Mr. Carey should have confined himself to English sieves or French sieves. He also objected to the phrase "over-liming." An engineer had only to see whether cement was sound or not; and he maintained that cement might blow without being over-limed, and that a slight excess of lime did not necessarily imply bad cement. He therefore asked Mr. Carey to substitute the word soundness for over-liming. He devised some years ago an apparatus for determining the soundness of cement,[1] in which he treated the cement at a temperature of 110°. He had lately made hot-water tests of cement, and found that he could blow any

[1] Minutes of Proceedings Inst. C.E., vol. lxxv. p. 228.

cement to pieces if it was subjected to the specified temperature of 180° long enough, and therefore boiling was not indicative of bad or good cement. A specification recently sent him stated that the cement "must be gauged, and placed in the testing moulds on plate glass. At the expiration of three hours, the casts were to be taken out of the moulds, and exposed to the air for twenty-four hours, after which they were to be immersed in boiling water and kept at boiling point twenty-four hours, during which time they must not show any signs of disintegration." He admitted that he was unable to advise the manufacturer what to do to comply with these terms. For ordinary purposes, they only had to find out whether it was sound or not; and that could be done without boiling, which had nothing to do with the constructive value of the material. He agreed with Mr. Bevan in objecting to the engineer living with the cement maker; the cement maker, however, was well able to take care of himself. He objected to it on behalf of the engineer; for if the engineer meddled, the manufacturer might turn round and say: "If you had let me make the cement, I would have made it comply with your requirements." Fifteen years ago he had endeavoured to induce the manufacturers to agree to a standard specification, and he was pleased to say that he failed, as such a specification would be greatly to the detriment of the cement industry and users. But a committee of members of this Institution, with others interested in the trade, might very advantageously formulate certain mechanical tests, which a cement should comply with, leaving the details of those tests to the individual requirements of the users; and if such a committee was formed, he should be glad to take an active part in it. When the failures at Aberdeen were first talked about, he made a great number of experiments, and arrived at certain conclusions, which were published three years ago.[1] He was surprised that Mr. Smith, reading a Paper three years afterwards, had not used those experiments to render his Paper somewhat argumentative and conclusive. Magnesia in cement, and magnesia as precipitated from sea-water, were two absolutely distinct matters. A very small percentage of magnesia in cement rendered it dangerous, because the lime in the cement combined with the silica and alumina at a lower temperature than the magnesia, and consequently the magnesia was left in a free caustic state, and expanded on hydration. He thought that 3 per cent. was the maximum for safety, though he had made cement with 5 per cent. of magnesia, which was perfectly good. One per

Mr. Faija.

[1] Society of Engineers, Transactions, 1888, p. 49.

Mr. Faija. cent., proposed by Mr. Hayter, was too low, because there were very few manufacturers on the Thames and Medway who could produce a cement with only 1 per cent. of magnesia ; the general percentage was about 1·8. Magnesia as precipitated from sea-water was simply in the form of a hydrate or carbonate, and was a perfectly inert material. The lime was dissolved from the cement, and the magnesia precipitated from the sea-water; but the lime was not dissolved, to the destruction of the cement, if it was sound; and as the lime from the outside surface was dissolved, a crust of lime and magnesia was formed which rendered the mass impervious to further destructive action. He had passed sea-water through blocks under a head of 21 feet, and found, like Mr. Smith, that after a time percolation ceased, because the pores of the concrete became filled with the deposit of carbonate of lime and magnesia, so that the briquettes through which the sea-water had percolated were stronger than those left in the sea-water without percolation. The analyses given by Mr. Smith showed that the failure at Aberdeen was due to bad cement or bad manipulation. This was evidently the cause of the failure; and it was a great pity that Portland cement should be depreciated by an error of judgment. Mr. Bamber's Paper was misleading with regard to the manufacture of Portland cement, for from the first line it would appear that it could only be made from chalk and clay. Portland cement might, however, be made from any materials which contained the necessary constituents. He was now making Portland cement, in Brazil, from a hard limestone containing 5 per cent. of carbonate of magnesia, with a river mud which was deficient in silica, and a pit clay which contained a very high percentage of silica; also, in North Wales, from a soft carbonate of lime which was the decomposed limestones of the district, with a pit clay; in Dakota, United States, from a carbonate of lime much resembling our grey chalk, with a river mud; and in Vancouver's Island, from a hard limestone consisting of a pure carbonate of lime, with a shale containing large nodules of septaria. In India, again, cement was being made from the Ghooting limes of the country, mixed with a calcite; and the old-established cement works in Madras were producing cement from shell lime, with clay. Blue lias was also available for the manufacture of Portland cement; and in Australia, he was making cement from a limestone very similar to the Indian Ghootings, but containing more carbonate of lime, and he was therefore adding clay. In each of these instances different machinery and appliances had been adopted, in order that the

reduction and amalgamation of the raw materials might be effected thoroughly and economically. Mr. Bamber's description, therefore, referred only to the manufactories on the Thames and Medway. The best cement was produced by a rapid calcination at a high temperature; and he quite agreed with Mr. Carey that the old form of kiln should be abandoned. He was convinced from the first that Mr. Ransome's cylinder process of calcination would never be successful, because the necessity of keeping the dried slurry moving during calcination was antagonistic to the principle of calcination; and he believed that the several cylinders which had been erected had been abandoned. Having experimented with every grinding machine which had been brought out, he put mill-stones, in preference, into some recent works, for though expensive and antiquated, unless the Dutrulle, or edge-runner principle was to supersede them, he knew of no other pulverizer giving the same results. He considered magnesia in Portland cement as so much lime, and not, as Mr. Carey stated, an adulterant, as fully explained in his Paper already referred to. The Dietrich apparatus was the most convenient for determining the carbonate of lime in a slurry, and Messrs. Griffin and Son were now making one more convenient to use than the one imported from Germany; but the calcimeter only determined the amount of carbonic acid in the slurry, and as the percentage of silica, alumina, magnesia, &c., might also vary in the raw materials, it was essential that the manufacturer should make repeated chemical analyses of his raw materials, in order that these variations might be determined. He disagreed with Mr. Bamber that turning over a cement reduced its tensile strength, for in his experience the tensile strength of a cement was almost invariably increased by aeration, unless, of course, it was continued too long. Mr. Bamber's theory that a cement sets first on the outside, thus forming a protective skin, might possibly be the case if Mr. Leedham White's theory was correct; but in a set cement, there was a certain percentage of combined water, which was evidence of crystallization. If Mr. Bamber's statement was correct, the interior of a piece of gauged cement would never set, which was not the fact, and he therefore thought that a cement, when mixed with water, sets evenly throughout its bulk. Mr. Faija.

Mr. L. F. Vernon-Harcourt said two or three years ago he constructed a small concrete fishery pier at Babbacombe on the Devonshire coast. In the specification he stated that there must be an analysis of the Portland cement supplied for that purpose. Two analyses, made for him by Mr. Carey, were given below, showing the proportions of the materials in the cement obtained Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt. from two different makers, which closely resembled the proportions that Mr. Bamber thought would make good cement:—

Constituents of Cement.	First Sample.	Second Sample.
Lime	59·22	61·20
Carbonate of lime	1·66	1·20
Silica	21·00	22·00
Alumina and ferric oxide	12·70	9·60
Magnesia	2·40	0·35
Alkalies, moisture, &c.	3·02	5·65
	100·00	100·00
Specific gravity		3·10

One of the cements had a specific gravity of 3·1, so that it was possible to get that specific gravity without specially asking for it. In one case the percentage of magnesia was 2·4, which, as far as the result of the work was concerned, did not seem to have any deleterious effect; and in the other, it was only 0·35, showing that it was quite possible to get a cement which had not as much magnesia in it as Mr. Faija thought would be the minimum attainable. The second sample of cement, at seven days, showed an average tensile strength of 483 lbs. on the square inch. Theoretically it would be desirable to get cement as fine as possible; but, on economical grounds, it was a question whether they should insist upon manufacturers giving a great degree of fineness, or whether it might not be more practicable to insist upon a certain proportion of fineness, and to regulate the amount of cement in the concrete according to the fineness obtained. As to the proportion of water for the concrete, they could judge better on the spot. It depended upon various considerations; upon the state of the weather, upon the wetness of the materials at the time, and also whether the concrete was to be put into water or not. Mr. Smith, in his Paper, said that the breaches in the south breakwater at Aberdeen were caused by compressed air in hollows in the breakwater. That was not a new thing to those who had to do with breakwaters. About eighteen years ago a Paper of his own was read upon Alderney harbour,[1] in which he pointed out that the commencement of the breaches in the breakwater were mainly due to the forcing out of the stones from the breakwater, in spite of the great force of the sea tending to force them in, by the compression of the air from the force of the waves. He was surprised

[1] Minutes of Proceedings Inst. C.E., vol. xxxvii. p. 72.

Mr. Vernon-Harcourt.

at the statement in Mr. Smith's Paper that heavy plant was required for making large blocks of concrete. In the case of the Babbacombe fishery pier it was impossible, owing to the smallness of the work, to have any large plant at all, and yet that pier was constructed of one single block throughout. It was quite easy, by depositing concrete in a mass, to make a pier practically solid throughout. The proportions of the concrete were, 1 of Portland cement, 2 of sand, and 4 of stones; large blocks of stone were embedded at intervals in the concrete above low-water level; and the outer face was formed with 1 of cement to 2 of sand. In that case there were no cracks that he could discern, although the pier had been finished for about two years; and there was no deterioration that could be noticed from the effect of the sea-water. The only injury that had occurred to that little pier was that the battering of the shingle, that accumulated on one side against the pier, during storms had caused a small abrasion of the surface near the shore. The most important point to engineers in the Papers was the question whether magnesia did or did not injure Portland cement; and Mr. Faija was quite right in pointing out that there were two distinct questions. They could tell whether there was magnesia in the cement in the first instance by having an analysis made, and that was a precaution that he imagined all engineers would now take to find out whether the cement they proposed to use had a small or large percentage of magnesia. It, however, was quite another matter if a cement which bore the required tests, and was of the proper composition, was liable, after being put into the work, to have the lime taken away from it and magnesia substituted in its stead. He had read some years ago Mr. Messent's report upon the failure of the Aberdeen Graving Dock, of which Mr. Smith's Paper was mainly a kind of summary. It appeared from that report that by the forced percolation of sea-water through some small blocks, it was possible to substitute rapidly magnesia for the lime in the cement. If that was the case, then eventually all the piers made of Portland cement concrete would deteriorate; and the rate of disintegration would depend upon the extent of contact with, and the frequency of change of, the sea-water. It seemed, however, to him that it could hardly be the case that the action of sea-water could, owing to its greater chemical affinity for lime than for magnesia, have that effect upon all concrete made with Portland cement with which it came in contact, for if it was so, works which had sea-water constantly playing upon them, such as breakwaters always exposed to the action of the waves and tide, would exhibit

Mr. Vernon-Harcourt. a certain indication on the surface, however smooth it might be, of deterioration going on. As far as his experience went, such deterioration was not visible in most cases. Chemical action between a liquid and a solid substance could not be prevented by the surface of exposure of the solid being only small, though the rate of change would necessarily be much more rapid with a powder than with a solid. The disintegration, likewise, of porous concrete, subjected to a head of sea-water, would be much more rapid than that of solid impervious concrete; but the surface of the solid concrete would still be exposed to the same chemical action. It was undoubtedly desirable not to let sea-water percolate through masses of concrete, and to make the concrete very solid and impervious, especially on the outer surface; but if there was this substitution of magnesia for the lime, surely it would be seen upon the smooth surface as well as in the interior. For instance, Babbacombe pier, showed no sign of any such action. The seaweed was growing upon the surface of the concrete pier, and if the surface was deteriorating, the seaweed would naturally scale off with the concrete to which it was attached. He therefore thought, though it would be desirable to have further experiments to ascertain the actual chemical action that took place, that by the process of setting, the lime ceased to exist in the cement in a free state, unless there was an excess of lime, a combination of silica and alumina with the lime being formed, that withdrew the lime from liability to the injurious action of sea-water; and they would consequently find in the future that they might have as much confidence in Portland cement as they had had in the past.

Mr. Lewis. Mr. W. B. Lewis said ten years ago he had to build a sea wall, on the south coast, $\frac{3}{4}$ mile long, entirely of concrete. He made a straight joint through the wall every 10 feet, to avoid the cracks from expansion and contraction so frequently seen in concrete walls. The wall was built of concrete made of cement, shingle, and sand, the interstices of the shingle being filled up with sand and cement, forming a solid mass; and he had not found a single crack in it after nearly ten years. On the top of the promenade behind the coping of the wall, a footway was laid, 7 inches thick and 12 feet wide, made of coarse concrete at the bottom, and fine at the top. Some of this had to be destroyed, and was thrown over the wall into the sea, where it had been lying ever since. The bottom of the concrete was very coarse, and even porous; but taking some of it up the other day, which had been exposed to the action of the sea for several years, it was like a piece of

granite, although the sea could get in to it. He would ask Mr. Bamber whether he thought that this concrete, made with an abundance of water, and in which the cement had entered into a perfect combination, would be affected by the magnesia in the sea-water? He wished for nothing stronger or better for retaining earthwork, or carrying weight, than that piece of porous concrete, which had been knocking about in the sea for six or seven years. He believed, therefore, that if good cement had been thoroughly well set with plenty of water, they need not fear the action of magnesia from the sea. Mr. Lewis.

Mr. Joseph Thomas said in thirty years' experience in concrete work, he had found that concrete made impervious to water was always best. Sixteen years ago, he had made concrete blocks, about 100 tons in weight, with gravel from the sea-shore, and impervious to water. In some cases, during bad weather, when gravel could not be obtained, the blocks were made from broken stone and rough sand, through which the salt-water passed; and when the frames were stripped off, a milky substance came out of them, though the same class of cement was used, and the blocks became so bad that they could not be used. He had used a great deal of cement; and if they gave makers some idea how it was to be used, whether in salt or fresh water, he believed they would get a cement suited to their requirements. In his opinion, hand-mixed concrete was the best, for then the concrete could be turned over dry two or three times, and the cement thoroughly well distributed; and he did not know any machine that would turn concrete over before it was wetted. In the construction of the Royal Albert Dock, some 80,000 tons of cement were used, and there were several machines working, but the hand-mixed concrete was the best. Some eight years later it was necessary to blow up one of the walls, composed of hand-made concrete, to form a new entrance; and the wall was thinned at the back from about 20 feet to 10 feet, with 30 feet of water in front, and no water came through; there were only a few air cracks. He had built concrete on solid trap rock, and got air cracks, which could not be due to any settlement. Seventy-five per cent. of the defects in concrete arose from mixing, and not from bad cement. After the shingle was gauged with the cement, it should be turned over in a cone, and then the cement would distribute itself, and the cone turned over again, so that the cement and shingle would be again thoroughly distributed. It should then be turned over wet enough to be all on a shake, and no ramming was then necessary; and if plenty of water was added, Mr. Thomas.

Mr. Thomas. it did not take the cement out of the shingle, but would drain off clear.

Sir J. Douglass. Sir JAMES N. DOUGLASS said he could go back thirty-five years, when he first commenced to use Portland cement, and in situations at sea as much exposed as at any part of the coast of this country, and he had never found any of the work allowing salt-water to pass through it. He had never seen any destruction of the surface; but, on the contrary, crustacea were found living very comfortably on the surface. He therefore believed that if care was taken in the manufacture of cement, there was no occasion for alarm. He always obtained the cement from an experienced manufacturer on the Medway, and kept it for some time, although it was necessary to use it as fresh as possible for the safety of the exposed tidal work. He selected the very best sand, coarse crushed granite from a mine in Cornwall, every particle angular, and as clean as possible. One part by measure of cement was mixed with one and a half of sand, with plenty of water, well worked together, the result being that there had been no failure of any kind. In cutting out portions of the work, the masons' tools were blunted nearly as much by the cement mortar joints as by the granite. He had seen very thin spalls, with a cement joint across the centre. If such work could be secured with Portland cement mortar, he did not see why it should not be accomplished with large masses of concrete, provided care was taken in the selection of the materials, and in forming the concrete blocks. In the works he had referred to, no air holes were ever allowed in the masonry, as at Alderney harbour, which led to the destruction of the breakwater there, by causing the face stones to be forced out, with receding waves, by the compressed air behind. They should never allow salt-water to enter the joints of exposed masonry or concrete work, and they might then be assured, with good cement, that the work would last almost for ever. If cement mortar made thirty-five years ago was still perfectly sound, surely with the improvements in manufacture, including finer grinding of the cement, it should give still better results.

Mr. Binnie. Mr. A. R. BINNIE said that he always divided concrete into two great classes; first, concrete in mass to sustain a weight, such as concrete in a foundation, and, secondly, concrete which had to sustain the pressure of water. The first class, as long as it was composed of an aggregate of sufficient hardness, might be easily made, for a few vacuities, if not very large, were practically immaterial. In the second class of concrete, however, which was

to resist water pressure, it became of the utmost importance that the concrete should be made absolutely solid. He had for years been trying to get his inspectors and contractors to make concrete so that, when broken open, there should be no holes in it above the size of a large pin's head. To accomplish this, abandoning theoretical proportions, they must deal with the substances they had at hand. If dealing with broken stone, such as the millstone grit, they must adjust the jaws of the stone-crusher so as to give a sufficient amount of sand to fill up all possible interstices; and then they must add the cement. In mixing the cement with the aggregate, the mixture must be made perfect in the dry state, otherwise a perfectly solid piece of work would not be obtained. When attempting to make solid impervious concrete, they must of necessity have water in superabundance, until the mass was made almost gelatinous; and then they got a perfect mixture. He had seen specimens of Portland cement, set in this way, polished by a lapidary, and presenting an appearance very similar to the heavy conglomerates in the Old Red Sandstone formation, which they might look upon as the perfection of concrete. He thought there had been something radically wrong, either in the cement, or the mode of mixture at the Aberdeen works. He could not understand how, when they mixed the concrete, these vacuities should have grown up, in the interior of the blocks, into which afterwards the sea-water injected the magnesia, which ultimately disintegrated them. Mr. Binnie.

Mr. J. Wolfe Barry said he had used large quantities of cement on dry land, and some in the sea; and he did not share the fear as to using cement for sea work, if proper care was taken in the manipulation and mixing, in the proportion of cement, and in the qualities of the gravel and sand. The failures that had taken place did not necessarily indicate objections in principle to cement; and engineers should not think they were going to have failures universally, because in one or two cases some mishap had taken place, which could be accounted for either by faulty cement or defective manipulation. Blue lias lime also in concrete and mortar of sea works had been relied upon with great confidence by many engineers; and numerous old works built of blue lias lime were excellent pieces of construction. It was, however, necessary that at least as much care should be taken in the use of blue lias lime concrete and mortar, as in using cement either in concrete or mortar. Failures had occurred at Hartlepool and Sunderland; and Mr. Charles Harrison, the Engineer of the North-Eastern Railway in charge of the Newcastle district, had asked him to Mr. Barry.

Mr. Barry. convey to the Institution some valuable experience. Mr. Harrison wrote:—

"Instances of complete decomposition of blue lias lime mortar from contact with sea-water have come under my notice, at the extension of the docks at West Hartlepool, and at Sunderland South Docks. The West Hartlepool new docks were constructed under my supervision as Resident Engineer; and the whole of the mortar used in the construction of the dock walls and entrance locks, with the exception of the hollow quoins and sills, which were set in Portland cement, was composed of 1½ part of blue lias lime, 1½ of clean sand, and ½ of forge cinders. The blue lias lime was made from Aberthaw pebbles collected on the shore at Penarth, and brought by ship to West Hartlepool, where it was burnt in kilns, and ground with the other components in mortar mills. During the nine years the works were in progress, numerous alterations, involving the pulling down and reconstruction of different parts of the masonry, were made, and in every instance the mortar was found to be harder even than the stone. The water was let into the docks in 1880; and in 1887 serious cracks and bulges in the wall were noticed. On examination, the whole of the mortar below high-water mark seemed to have expanded and become as soft as putty for a considerable distance from the face, while above that level it remained as hard as ever. This rapid decomposition of the mortar, similar to that stated in the Papers with regard to Portland cement, may perhaps be attributed to the large percentage of carbonate of lime in the Aberthaw pebbles. On mentioning this failure to Mr. Wake, the engineer to the River Wear Commissioners, I learnt that in the old walls of the south dock at Sunderland, which were built in 1850, and pulled down for the construction of a new entrance in 1887, the blue lias lime mortar had perished in the same way, and was quite soft. On the other hand, blue lias lime mortar was used in the construction of the walls, &c., at Tyne dock, parts of which were pulled down this year in order to construct the new entrance, and the mortar was as hard as possible; the only difference in the specification for the mortar at West Hartlepool from that at Tyne dock being the substitution of forge cinders for Pozzaolano. I can only suggest that the sea-water at Tyne dock has been so diluted with the fresh water of the River Tyne as to lose some of its decomposing power."

These were alarming statements; and it appeared that when an engineer thought he had finished his work creditably, failures might occur at some future time. The important point in such cases was, whether the decay of the mortar really resulted from the action of sea-water. In numberless instances, with sea-water constantly rising and falling against masonry built in blue lias lime, no prejudicial effects had been observed, and cases of failure were extremely rare. He concluded that, as in cement, the treatment and manipulation of the blue lias lime should be most carefully studied. He had lately executed a large work in the neighbourhood of the Aberthaw lime pebbles, and had used an immense quantity of blue lias lime mortar. At the Barry Docks, before deciding on the mode of treating the lime for use in mortar, a series of experiments were instituted in masonry specially built

with different parts of lime and sand, and treating the lime in different ways. The general result proved that slaking the lime before admixture in the mortar mills was of cardinal importance in using blue lias lime. They could not be too careful in slaking lime. He had noticed in some specifications, particularly of the Hartlepool and Tyne docks, that it was ordered that the mortar should be mixed as dry as possible, and that previous to admixture the lime should be kept in covered sheds. Several experiments were tried at Barry with lime treated in this way; but although the mortar set perfectly hard and apparently satisfactorily, the blocks of masonry burst to pieces in a few weeks, as though they had been broken by dynamite. He ultimately decided that the lime should be slaked for a considerable time before it was used, and he had found that in that way the danger was avoided. At Barry Docks the lime, soon after being drawn from the kilns, was completely wetted in sheds, and covered up with sand for not less than seven, or more than fourteen days, before being used. In making the mortar, the lime was mixed thoroughly with water, and with $1\frac{1}{2}$ of sand to 1 of lime, and $\frac{1}{4}$ of hard burnt clay was added, the whole being thoroughly treated in mortar mills. The results, after six years' experience, seemed thoroughly satisfactory. In one instance, in a viaduct on the Barry railway, in which, by inadvertence, the lime had not been slaked for seven days before being used, large blocks of limestone masonry were raised completely off their beds, although they had been built for a considerable time, and the work was to all outward appearance perfectly sound. When insufficiently slaked lime was used, moisture slowly percolated into the joints, first attacking the outside portions of the mortar, and then gradually finding its way to the interior; and chemical changes took place, producing a great disruptive force. He believed that the same results might be experienced in cement with a large proportion of lime as in the case of blue lias lime; and the recommendation to use plenty of water, and to allow a considerable time for absorption, entirely accorded with his views as most important in all admixtures of mortar or concrete. Mr. Barry.

Mr. H. E. Jones said he had special experience of cement concrete where exposed to strong alkaline solutions. It was the presence of a weak alkaline solution in the case of the Aberdeen breakwater, to which its disintegration was attributed. He had for many years been making cement concrete reservoirs, where the hydrostatic pressure reached 50 feet head, with the utmost safety and permanence, and also reservoirs for the retention of strong Mr. Jones.

Mr. Jones ammoniacal solutions, without any disquieting result. He attributed that to his invariably indurating the surface exposed to the liquid by hand-floating. It was a question of permeability; and he invested the surface, although many hundred square yards in area, with an absolutely watertight skin of indurated cement, enamelling the surface. The result had been completely successful; and the cement had been exposed to violent chemical action far exceeding what could possibly arise from sea-water. The impermeability of well made and rendered Portland cement concrete had been tested by him in the construction of vessels, with wrought-iron covers, 36 feet long by 28 feet wide by 6 feet deep, for gas purification, in which absolute tightness from leakage of gas had been secured. Looking at the low specific gravity of coal-gas as compared with liquids, and its very penetrating nature, this was probably the severest trial that Portland cement had ever been put to. These purifiers had been at work for six or seven years with satisfactory results. The wrought-iron cover was attached to heavy joists of wrought iron, bedded to half their depth in Portland cement concrete; and the joint between the metal and the cement concrete had remained intact from the first. It was to be regretted that the history of the concrete at Aberdeen had not been more completely given; but it was stated that an undefined quantity of rubble was added to the concrete. Thus large fragments of rubble intersecting the walls transversely, and perhaps in contact in places, practically destroyed the tensile value of the concrete, and offered facilities for the permeation of liquid. The best plan was to use very clean stones, a large proportion of sand to secure a good bed for the larger stones, and not less than 1 in 6 of heavy Portland cement finely ground. It would be a distressing thing to members of his branch of the profession, who were constantly making large reservoirs, as much as 250 feet in diameter and 50 to 60 feet deep, where most surprising results were obtained from concrete, and where the work stood well although there might be a settlement, to be told that Portland cement was unreliable. There was an enormous tank not far from London, which had gone down bodily on one side, and had been brought back to the level by weighting it, without any sign of a crack. There was no other possible material that would stand that, and therefore he hoped that no sense of insecurity would be felt as to the value of Portland cement concrete.

Sir R. Rawlinson. Sir ROBERT RAWLINSON: What thickness was your wall of 50 feet deep?

Mr. Jones. Mr. H. E. JONES: Something like 6 feet.

Colonel H. C. SEDDON said as failures were always instructive, he would describe a very singular failure which took place at some works in Portsmouth harbour, whilst he was Superintending Engineer at Portsmouth Dockyard. Neither that failure, nor any reasons put forward for the failure of concrete at Aberdeen had in the least degree shaken his faith in the durability of good Portland cement concrete when properly applied. He did not consider that sea-water was the culprit that some people tried to make out; and it was possible that whilst their ingredients might be right, and the mixing right, there might be some local conditions which led to the failures. The work to which he referred at Portsmouth was carried out some four or five years ago. They were laying a foundation for a lock, which was constructed entirely of concrete, at the entrance to the new torpedo range at the top of the harbour. The foundation consisted of a 5-foot bed of concrete, composed of 9 parts of clean shingle and sand to 1 of cement. It was executed by very good contractors, but the concrete refused to set from first to last, though left for several months. The top hardened a little when dry, but the mass was rotten throughout, and when cut into, fell to bits like a bed of gravel. Three or four large holes, from 12 to 18 inches deep and 4 or 5 feet in diameter, were dug in it, which rapidly filled up, to within a few inches of the surface, with water soaking up through the concrete. This water was brackish, and both smelt and tasted strongly of sulphuretted hydrogen, the presence of which was also proved by chemical analysis. When undisturbed, the water at the bottom of the holes was of a deep green colour, whilst the upper part was colourless, except that a white lime precipitate floated on the surface like a film, and also coated the sides and bottom of the holes. When stirred up, the green colour pervaded the whole, though it soon sank to the bottom again when left alone. Thinking that this water must come from a spring rising from the chalk, which had been met with about the centre of the foundations and led off before the concrete was put in, the water from which was brackish and impregnated with red oxide of iron, he bored down through the concrete and allowed it to rise in the hole, with the result that the bore-hole was always full of this red iron-stained water, which merely tasted brackish and irony, forming a strong contrast to the offensive deep green water in the other holes. It seemed, therefore, that this spring-water acquired its deep green colour, and its offensive smell, in soaking up through the concrete. Blocks of 9 to 1 concrete made with the spring-water, drawn direct from the hole bored down through the

Col. Seddon. concrete, set properly. The green water appeared to have no deleterious effect upon neat cement briquettes, or on mixtures up to about 3 to 1; but beyond that, as they became more porous, the bad effect increased rapidly, 9 to 1 concrete blocks made with it being perfectly rotten; whilst blocks of 9 to 1 concrete specially made with pure sea-water and very good cement, and left to set for at least three weeks, when merely laid on the top of the damp rotten concrete, very rapidly became rotten themselves. If immersed in the green water to half their depth, the deterioration was less rapid; but when totally immersed, no deterioration could be detected, showing that the oxygen of the air took an active part in the decomposition of the blocks so treated. A piece taken out of the bed of rotten concrete, and allowed to dry, hardened very considerably in the course of about ten weeks. Some other spring might have broken out after the concrete was put in, but they were unable to discover any. On mentioning the matter to Mr. Boulnois, then Borough Engineer at Portsmouth, he was told that a similar failure once occurred to a small concrete foundation on the shore nearer the mouth of the harbour; and he believed Mr. Boulnois resorted to brickwork in cement. In his case, deciding to treat the rotten concrete as if it was a firm bed of gravel, he took off the top 18 inches, drained off the water, and when dry, laid asphalte over the whole area to prevent the rising of the objectionable water, trusting to its being ultimately kept down by the weight of the sea-water above it when once the work was finished, and the water let into the range. This plan was perfectly successful, and the concrete work was carried on above without any further trouble. The cement used in the concrete which failed was very slow-setting; and it only just passed the strength test of 250 lbs. per square inch after seven days in water, though the manufacturer, by dint of a minimum of water and a maximum of ramming, managed to obtain much higher results. It was finely ground, nearly all passing through a 2,500 mesh. Its weight was only 86 lbs., instead of 90 lbs. per cubic foot; and he was not pleased with the colour of the cement when made up into pats and briquettes; but he did not then consider he had sufficient grounds for rejecting it, though he believed it to be both over-limed and under-burnt. On retesting the cement after the failure of the concrete, its strength varied so much, in addition to its light weight, that although the failure of the concrete could not be attributed to the cement, he would not allow any more to be used on the works. The cause of this failure was clearly not deposition of magnesia from sea-water, nor excess of magnesia in the cement,

which amounted only to about 1·6 per cent. He believed many failures might be traced to the instability of the cement, due to its chemical composition or defects in manufacture, very frequently to under-burning or to defective aggregates, greatly aided by bad mixing or by being starved for want of, or drowned by too much water. He totally disagreed with Mr. Bamber's remark, that "cement is often stored for some weeks and turned over to lessen its tensile strength, with the mistaken notion of making it safer"; for there was overwhelming evidence that Portland cement, as delivered on works, could seldom be safely used without exposure to the air, and that its strength was increased rather than lessened by such exposure. In Mr. Carey's specification, no reference was made to the quality or quantity of water to be used in making up the briquettes; and he would suggest that pure fresh, or even distilled water should be specified, in the proportion of not more than 25 per cent. by weight, and not less than 22 per cent. The requisite amount of water would vary with the nature and freshness of the cement; but a minimum was necessary to guard against an abnornal strength due to ramming, and a maximum to prevent weakness due to porosity and drowning the cement. No comparison could be instituted between two sets of briquettes, one made up by ramming the cement into the mould with a maximum of force and a minimum of water, and the other by merely pressing it in with the point of the trowel and a fair amount of water. For any reliable comparison, some means of applying a uniform pressure in all cases was required. Col. Seddon.

Mr. H. K. Bamber, in reply, observed that Mr. Carey, in his analyses of Portland cement (Appendix VII), gave in one case alkalies and loss 5·60 per cent., and in the other 6·61 per cent.; but most likely the greater portion of this should have been lime; and analyses with so great a loss were useless. To test the permeability of concrete, he had two blocks made, one with the full quantity of water it could take, and the other with half that quantity. A pipe was inserted into each block as far as the middle, and when set, 30 feet of iron pipe was screwed into it, and a tank placed at the top, which was filled with sea-water. In the block mixed with the full quantity of water, there was no sign of water passing through, or any milky fluid appearing for the three days during which the pressure was continued. In the other block, mixed with half the quantity of water and similarly tested, a milky fluid flowed from all sides within half-an-hour. Moreover, in mixing the concrete, it was found that when the Mr. Bamber.

Mr. Bamber. full quantity of water was used, it was easy to get one-eighth more sand, shingle, and cement into a box, 18 inches cube, than when only half the quantity of water was used. This showed that it was advantageous for a contractor to mix the concrete as dry as possible, as thereby, in every 8,000 cubic yards of concrete, he would save 1,000 cubic yards of material. Air must fill up the vacant one-eighth of the space, and hence water percolated through concrete mixed too dry, washing out a lot of the cement, and forming milky fluids, which, in the case of sea-water, would contain magnesia as well as lime. The salt contained in sea-water had not the slightest effect upon thoroughly good concrete, which should be impervious to water. Magnesia found in the deposits only showed that the concrete had gone wrong; and then some of the lime being dissolved, and coming into contact with the salts of magnesia in the sea-water, precipitated the magnesia as hydrate, which could not possibly cause expansion. Magnesia, to be injurious, must be in the cement itself, and its effect there he had already given. There could be no doubt as to the cause of the Aberdeen dock failure. In the first place the original dry cement (p. 63) contained 8·18 per cent. of carbonate of lime, and 11·26 per cent. of hydrate of lime, showing that this cement was never properly burned, or had been spoiled by exposure to the weather. How any engineer could think of using such a cement, if he knew of its composition, he was at a loss to understand; and if he omitted to have it analysed until afterwards, the proper precautions requisite in such a large work were neglected. Again, it appeared from Mr. Smith's Paper, that very undue economy was used in working this cement into concrete. For the entrance, caisson chamber, dock-bottom, and the head of the dock, he used 1 of cement, 3 of sand, and 3 of stones, with rubble added *ad libitum;* and for the side walls, 13 feet thick, 1 of cement, 4 of sand, and 4 of stones, with rubble as before. The facings, &c., were in better proportion; but cement having the composition given by Mr. Smith was perfectly useless in such, or any proportions; and £16,000 had been spent in patching up works, which, with properly tested cement, used in less economical proportions, would have been sounder from the beginning than it could ever be now, and would have cost much less. He had been found fault with by Mr. Faija for giving the average quantity of water that should be used to each cubic foot of cement, in case broken bricks or other porous materials were used. He referred to ordinary sand, shingle, and cement; and the engineer in charge of the works would know that if his bricks were dry, he must soak

Mr. Bamber.

them with water before putting them into walls, whether lime mortar or cement and sand were used. Cement was usually sent out in bags containing 200 lbs.; and this would be about 2 cubic feet, and would require about 80 lbs. of water (8 gallons) for proper mixing. Mr. Hayter mentioned having tested cement that was required in a hurry by putting it in hot water; but he (Mr. Bamber) failed to see what use that could be, and what it proved; and an engineer would be most unwise to trust to that to tell if he was getting good cement. He failed to get Mr. Bevan to fix the percentage of lime in cement when over-liming commenced. With regard to Mr. Bevan's fracture-curve of briquettes gauged with different quantities of water, his (Mr. Bamber's) son, the manager for Messrs. Pattrick and Son, of Dovercourt, where his experiments were chiefly made, mixed by hand two briquettes with 16 per cent. by weight of water, and two with 17 per cent. of water; and he himself mixed the same cement with 20 per cent. by weight of water. At seven days, the briquettes with 16 per cent. of water broke at 480 lbs. and 510 lbs.; those with 17 per cent. of water broke at 570 lbs. and 575 lbs.; and his own with 20 per cent. of water broke at 610 lbs. He found no difficulty in mixing briquettes by hand, and much preferred it to any machine mixing; and on testing duplicate briquettes, the breaking strain varied but little. The above results were quite the opposite to Mr. Bevan's statement; but he believed the difference was mainly due to the different quality of the cement. He quite agreed that the engineer had far better not interfere with the manufacture of the cement, for if he did so, he could not reject the cement without rejecting his own handiwork. The engineer should content himself with having the cement, after delivery, put to all the tests given in his Paper, and leave the manufacturer to manage his own business. The general average of cement was good now, but there must sometimes be a difference in the quality of different kilns of cement; and cement manufacturers were not foolish enough to send inferior cement to an engineer who thoroughly tested it. He also agreed with Mr. Bevan in preferring the older fashion with large works, because the slurry, having more water, could be passed through finer sieves, and not show subsequently the portion of unmixed chalk, which was the invariable rule in using the Goreham process; and if the cement had to be thoroughly mixed again after manufacture, he saw no economy in the working. Moreover, he believed the wear and tear in the kilns would be found to be much greater, the only advantage being that less land was required for the works. With regard to Mr. Leedham

Mr. Bamber. White's theory of the use of the water in cement, he could only say that no chemical action or setting would take place without this water, and even if there was enough water to allow the first setting, the presence of plenty of water was still absolutely necessary to effect the chemical combination of the excess of lime with the silica and the sand. When shell sand was used, there was no chemical action between the shell, which was carbonate of lime, and the lime of the cement; and shell sand was therefore unfit for mixing with Portland cement. Mr. Carey mentioned the effect of dirty water in preventing the setting of cement, which was a well-known fact, as well as that, if the sand used contained finely-divided earthy matter, it would not set properly. If there was any doubt about the sand, it should be thoroughly washed before being used. This Paper was said by Mr. Faija to be misleading with regard to the manufacture of Portland cement, because he did not mention everything from which it was possible to make cement having a similar composition to Portland cement. Seeing, however, that in England not more than about 1 ton in 10,000, or perhaps less, was made from anything but clay and chalk, and engineers used no other in large works, he failed to see the force of the objection. Mr. Faija also disagreed with what he called his (Mr. Bamber's) theory that cement sets first on the outside, though all he had said was that small test-pats, although setting all through, became hard and impervious to water on the outside first, by exposure to the air and partial evaporation of the water. Mr. Faija and others held to the opinion that cement, which was bad and unsafe when new, becomes safe and good by being exposed to the air by repeated turning. If a cement was properly made, even with 61 per cent. of lime, and finely ground, it was perfectly safe to use new, if mixed with the full quantity of water; and as it always remained a month to await the twenty-eight days' test, that was quite old enough for a good cement. A cement that was bad and unsafe to use without continued turning and exposure to the air would never become a good and reliable cement by this process, which cost money that might be better expended in getting a more costly and reliable cement at first. It was on account of this belief that in his block experiments he purposely used cement hot from the grindstones, and if small blocks stood, so would large blocks, if similarly treated. The only object of the turnings and exposure was to slake some of the lime in the cement, and when plenty of water was used in gauging the concrete, every atom of the finely-ground cement would instantly become slaked, and if once slaked, no further expansion could

take place. He was certain that, in time, this would be admitted by engineers who were open to conviction, and who used cement as he described. Mr. Bamber.

Mr. A. E. Carey, in reply, said that concrete, as a material for structures in the sea, was on its trial, a matter of vast importance to harbour engineers; and it would be lamentable should doubts be causelessly raised as to the permanence of Portland cement concrete for harbour works. This question must be fought out on chemical evidence; but Mr. Bamber's Paper did not support the theory that magnesia, not in a caustic form, destroyed concrete. If the contention of Mr. Smith's Paper was correct, it was difficult, as pointed out by Mr. Vernon-Harcourt, to avoid the conclusion that all concrete structures in marine waters must have within them the seeds of chemical dissolution. It was well known, however, that concrete in the sea, especially in tropical waters, became rapidly covered with seaweed, which indicated that the outer skin of such structures was not being corroded by the chemical action described. He had just completed a breakwater in the open sea, constructed entirely in Portland cement concrete, 680 yards long, and extending into 43 feet of water; and the frontage of the quays in the sea, protected by the breakwater, was about 1,500 yards. The work had occupied six years, and about 200,000 cubic yards of Portland cement concrete had been deposited in the sea. The mysterious magnesian malady described had not broken out there, nor had it in scores of foreshore and sea works in cement concrete scattered all over the world. The inference was that, in the works which had failed, either the cement was defective or it was improperly handled. In the analysis of the dry cement used at Aberdeen (p. 63) there was a great excess of lime in a caustic form, which rendered the bursting up of the concrete natural; and there would be nothing unusual in the deposition of magnesia salts in the pores of the work. He believed concrete, made with sound cement and properly handled, where ammonia was not largely present, might be employed with absolute confidence for sea works. Mr. Smith gave a series of experiments in Appendix IV of his Paper, almost identical with those described in Appendix III of his own. Mr. Smith's experiments did not appear to support his theory, as he did not state that the experimental concrete blocks swelled or cracked. As to the chemical analysis of Portland cement, Mr. Hayter said, "the lime should not exceed 60 per cent., and if it could be reduced to 55 per cent., it would be better." He would call special attention to the figures given in page 42, where sample A was cement burnt by the Joy Mr. Carey.

Mr. Carey. process, and the analysis showed only 54·85 per cent. of lime, but the tensile tests, especially the sand tests, were very high. The neat tests averaged $593\frac{1}{2}$ lbs. per square inch at seven days, and $784\frac{2}{3}$ lbs. at twenty-eight days. The 3 to 1 sand tests averaged $223\frac{2}{3}$ lbs. at seven days, and $383\frac{2}{3}$ lbs. per square inch at twenty-eight days. Mr. Smith stated (p. 55), "The free carbon dioxide in sea-water forms a film of carbonate of lime on the skin of all immersed concrete, and ultimately destroys it." If this was correct, the carbonate of lime washed down from chalk cliffs near concrete structures ought to destroy them, whereas there was no evidence of such a rusting action. Mr. Leader Williams' comparison of the relative values of hand- and machine-mixed concrete was interesting. The Carey and Latham concrete machines were in use on the Manchester Ship Canal works, and in these machines the quantity of water could be measured and regulated, and there was also a double mixing, first dry and then wet.[1] On the Newhaven Harbour works, the quantity of water used in concrete making was constantly remarked upon; but he was certain from that, and subsequent experience, that a less quantity would have resulted in inferior work. He found that, using good clean shingle or stone and sharp sea sand, about 22 gallons of water per cubic yard of raw materials gave the best results; but a hard and fast rule could not be laid down, owing to the variation in the water-absorbing capacity of the raw materials. In one cubic yard of raw materials, taking 15 cubic feet of shingle or stone, $7\frac{1}{2}$ cubic feet of sand, and $4\frac{1}{2}$ cubic feet of cement, and adopting Mr. Bamber's rule of 40 lbs. of water per cubic foot of cement, the quantity of water would be 180 lbs., or 18 gallons, which, considering the greater bulk of the materials handled, agreed fairly with his own experience. The apparent discrepancy stated by Mr. Henry Law did not exist, as shingle or dense stone and sand would not absorb any material portion of the water used for mixing. The wetting of the shingle or sand would account for some excess over the experimental quantity of water arrived at by Mr. Bamber. Mr. Bevan rather misrepresented the inspection he advocated of the manufacture of cement, which was the independent inspection of cement for public works by experts; and he thought that cement makers would be wise to give every facility to enable engineers to satisfy themselves as to methods of production. Makers knew as well as contractors that if cement was once delivered on to a work, the chances were twenty to one

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 102.

it would be used, even if it did not come up to the specification. Mr. Carey. He always began at the other end, and prevented delivery till he was satisfied as to quality. On no other terms would he allow cement to be used on any work for which he was responsible. A cement inspector, having a good practical knowledge of cement making, would see at a glance if works were being carried on in a slovenly manner, or whether scientific accuracy and skilled attention to detail were secured. Without living on a maker's works or managing his business for him, such an inspector could tell the engineer many facts, which might perhaps prevent a lamentable failure in the finished work. With regard to storage capacity, in three cement factories built by him, he had found a cement store capacity of ten times the weekly output work well. He did not mean that cement requires ten weeks' storage before use, but this amount of warehouse capacity suited the trade exigencies of those particular works. He was now building a fourth factory in the north of Europe, and was providing a larger warehouse to allow for winter storage. Mr. Bevan objected that this storage for a 3,000-ton factory meant a warehouse capacity of 30,000 tons, though apparently not objecting to three months' supply, or over 70,000 tons, of slurry. When two materials of different specific gravity, blended with 40 to 50 per cent. of water, were allowed to settle in the "settling" back, it was certain that the heavier particles would sink to the bottom, and that strata would result. Mr. Faija criticised the standard specification he submitted. His specification stated "specific gravity to be 3·1 after exposure fifteen minutes in a desiccator at 212° Fahrenheit," and he did not think there was any difficulty in obtaining such cement, nor should he recommend cement of a less specific gravity, under these conditions, to be used for any important work. Mr. Faija objected to having fineness taken partly by English and partly by French measure, but if the measures were understood by users, it mattered little whether they had an English or a French name. With regard to tensile strength, Mr. Faija did not submit any figures, but appeared to indicate a sliding scale. Although the figures he (Mr. Carey) had given would not absolutely insure a good cement, for no specification of tensile strength alone could do this, they were fair standard figures of good cement as now produced. Having tensile tests at three different periods, in case of a partial non-compliance with the terms of the specification, the engineer could use his discretion in passing the cement. He could not follow Mr. Faija's remarks on over-liming, nor could he agree with him that "an engineer had only to see whether

Mr. Carey. a cement was sound or not." Soundness, as applied by Mr. Faija, was synonymous with absence of over-liming. Over-liming was the *raison d'être* of this discussion; and it was of vital importance for a cement inspector to satisfy himself upon this point. With regard to a standard specification, he doubted whether a committee would agree unanimously on a normal test, and, if unanimous, whether their specification would be accepted in this country. It was impossible to argue from foreign countries, where the impress of Government regulations was on almost all industrial developments, that similar rules would be likely to be adopted in this country. He was surprised that so little reference had been made to fine grinding. Probably the average percentage of residue on the 32,257 mesh, with Portland cement as now produced in England, would be quite 40 per cent. The residue on this mesh had practically no cementitious value, so that out of each ton of cement, 8 cwt. was little better than clinker sand. A few English makers made a speciality of fine grinding; but he considered that, taken all round, the continental makers excelled us in this respect. He strongly advocated skilled manual gauging, for the experienced gauger could tell by instinct in manipulation the grade of any sample of cement, and that was all lost by any mechanical substitute, without insuring uniformity of test. From the drift of this discussion a reaction might set in against high tensile tests for cements; but it entirely depended on how such tests were attained, whether they were good or bad. With slurry of correct proportions, perfectly blended and ground so as not to leave more than 6 or 8 per cent. on a 22,500 mesh, with the best system of burning, and with dry grinding to leave 30 to 35 per cent. on a 32,257 mesh, cement might be produced yielding 400 to 500 lbs. per square inch at seven days, 600 to 700 lbs. at twenty-eight days, and steadily increasing in tensile strength to three years, or if gauged with sea-water, to about ten months, the colour of old samples of cement on fracture being a deep purple black, and their physical structure that of a dense natural stone. The strongest cement was the best cementing material, other conditions and qualifications being equal, so that unnecessarily to depress the standard of strength was merely placing a less perfect building material at the disposal of engineers.

Mr. Smith. Mr. William Smith, in reply, stated that the object of his Paper being to place on record investigations made by Professor Brazier, Mr. Pattinson, Mr. Messent, and himself, necessitated quoting short passages from reports by all these gentlemen, to elucidate the subject. The Papers upon Portland cement and its testing had no

practical bearing on his discovery, the whole of the Portland cement Mr. Smith. used at the Aberdeen Harbour works during the last twenty-three years having been tested by Mr. W. D. Cay, himself, Professor Brazier, Mr. Messent, and Mr. Pattinson, and proved to be of the best quality, and most suitable for marine works. A remit was made by the French Government, in 1888, to Messrs. L. Durand Claye, and P. Debray, engineers of the Ponts et Chaussées, who conducted an elaborate series of investigations upon the action on Portland cement of a solution of sulphate of magnesia of the same strength as contained in sea-water; and the results completely corroborated the theory given by him. Had a committee of qualified and disinterested persons been appointed by this Institution in 1888 (when he sent in his Paper), to investigate the action of sea-water upon Portland cement, and report, an authoritative result would have now been provided. To Mr. Hayter's mention of Maryport docks, and Belfast graving dock, might be added a graving dock recently constructed on the Tyne, one on the Clyde, Buckie Harbour works, Portlethen breakwater, and other small harbour works in Scotland. The bulk of the cement used in building the south breakwater at Aberdeen, all the under water portion of which had deteriorated by chemical action, was supplied by Mr. Bevan's firm; and the first contract entered into by him on behalf of the Aberdeen Harbour Commissioners was with the same firm, the whole of the cement supplied being of first-class quality. Mr. Bamber, in his remarks on p. 104, had been misled by an error in the title, "Analysis of Original Dry Cement" (p. 63), which should have been, "Analysis of Original Cement in Test Briquette." The presence of hydrate of lime was due to the water added in making the test-block which was analysed, none of the original dry cement being available. The deterioration of porous Portland cement concrete under filtration of sea-water, was due to the chemical force developed exceeding the cohesive force of the cement. Magnesia was a by-product of this action; and its presence was merely an indication that this action had taken place. His Paper, if fairly considered, answered completely every objection urged in the discussion. The following was a summary of his conclusions: (1) That the cause of the expansion and deterioration of concrete was the chemical reaction between the whole of the lime in the Portland cement, and the acid and basic constituents of sea-water, which replaced the cement with a bulkier and non-cementitious compound of sulphuric and carbonic acids, magnesia, and lime: (2) That this reaction was facilitated by the permeability of the mortar,

Mr. Smith. and accelerated by an unbalanced pressure forcing the sea-water through the concrete: (3) That the remedy and preventive of such action on concrete, was to make the concrete of such proportions of materials as to be impermeable. These conclusions were confirmed by an independent investigation subsequently made by Mr. Messent, with analyses by Mr. Pattinson. From a further series of observations and experiments, he (Mr. Smith) arrived at the following additional conclusions bearing upon the durability of Portland and Roman cement under chemical action: (1) That the weakest proportions of Portland cement concrete, under a head of sea-water, which could be relied upon as durable and sufficiently impermeable, were 1 cement, $1\frac{1}{2}$ sand, and 3 stones, an increase in the proportions either of sand or of stones making the concrete permeable: (2) That rubble masonry in Portland cement might generally, in a stone district, be built at the same price as equally strong and impermeable concrete: (3) That magnesia in Portland cement was only weakening when a higher proportion was present than 2 per cent.: (4) That the presence of 2 or 3 per cent. of sulphuric acid in Portland or Roman cement did no appreciable harm: (5) That the constituents of Portland cement were in a very feeble state of chemical combination both before and after hydration, the whole of the lime and silica being separable by digestion in slightly acidulated water: (6) That the setting of cements was an imperfect crystallization, taking place on the restoration of the water of crystallization to the lime and alumina: (7) That Roman cement had valuable properties of withstanding the chemical action of sea-water, and forming quick-setting mortar, which might be increased by fine grinding. The mechanical influence of waves was enormously increased by the compression of air in cavities, or open joints of dry built blocks. The combination of these mechanical and chemical destructive forces was the chief cause of the destruction of sea works. The remedies for both evils were :—(1) That sea works should be constructed of impermeable concrete or masonry in perfectly homogeneous structures of bonded and grouted blocks (not necessarily heavy blocks): (2) That, where practicable, solid masonry should be built in mortar composed of not less than equal measures of sand and cement: (3) That cheapness by the use of permeable compounds, or concrete rubble, should not be attempted. So far from his deprecating the use of Portland cement in sea works, the moral his Paper conveyed was the more liberal use of Portland cement in concrete or masonry of proportions sufficient to insure perfect impermeability. The graving dock repairs were executed

at his suggestion in Portland cement, in place of Roman cement specified by Mr. Messent. The proportions of the concrete works which had been affected by sea-water at Aberdeen, were fixed in pursuance of the advice of the late Sir John Hawkshaw, and Mr. Abernethy, consulting engineers for the Aberdeen breakwaters, and of Mr. Kinipple, the consulting engineer for the Aberdeen graving dock. His observations could only be corroborated by engineers who had had prolonged experience in the maintenance of large sea works, or concrete graving docks, like Mr. Hayter, Mr. Joseph Thomas, Mr. Messent, and others. In addition to the corroboration of his observations by these engineers, and by the report of Messrs. Durand Claye, and Debray, he had received a letter from Dr. Albert Busch, Chemist of Karlsruhe College, Germany, in which he said:—"I made some experiments on the same subject, and have published some of the experiments in Dingl: Polytechnical Journal. My experiments were made in London, and agree on the whole with yours." He (Mr. Smith) considered that whatever the value of the discussion upon his Paper, it should not be closed without his sincere tribute of respect to Mr. Messent, for his valuable investigation into the influence of sea-water upon Portland cement mortar and concrete, and his able report thereon to the Aberdeen Harbour Commissioners. Mr. Smith.

Correspondence.

Mr. William Sowerby believed that engineers, when engaged abroad, might require to know from what combination of other materials good hydraulic mortar or cement could be made, when neither Portland nor any other known cement were available. Mr. J. Brunton, formerly Chief Engineer of the Scinde Railway, had told him that when engaged on that line, he was obliged to manufacture hydraulic mortar from the materials on the spot, and did so with perfect success. "Khunker," or lime nodules, found in most parts of India, supposed to be broken up coral reefs, after calcination was mixed with burnt clay, calcined ironstone, and sand in about equal proportions, and ground and amalgamated in a mortar mill. In another part of India, he (Mr. Sowerby) adopted a very similar plan for making hydraulic mortar with equal success. In some of the amygdaloids and conglomerates found in the lower Himalayas, there were huge masses of very hard boulders and beds, in which the cementing matter was largely composed of peroxide of iron, associated with lime and silica. It was from examin- Mr. Sowerby.

Mr. Sowerby. ing these conglomerates that the idea of forming a similar cement artificially was obtained; and he found that an admixture of calcined iron ore with lime produced a very hard hydraulic mortar. In Southern India (Madras), shells were frequently used for making mortar; and it was customary to mix a quantity of coarse sugar with it, which rendered plaster very hard and free from those unsightly cracks which were seen here. The Romans, in their cements, were said to have used gluten obtained from wheat; and there was an old Roman arch at Lincoln where the joints were very fine, and the mortar was supposed to be mixed with this gluten. A short time ago a sample of the refuse from copper ore, known as "Blue Billy," was brought to him to try to utilize it. It contained a large quantity of iron, and proved capable of being utilized for making hard stone cement, the idea being suggested by his experiences in India and elsewhere. Similar hard conglomerates were found in the overburden at the Rio Tinto mines, in other parts of Spain, and in California, held together by natural cements containing a large percentage of ferruginous matter. The laterites of Southern India, of which the cathedral of Goa was built, were hard ferruginous conglomerates; and similar hard beds, found in Guzerat, were used for building bridges. Quite recently he saw a new variety of cement of interest to sanitary engineers. At a railway station, a workman was taking up the drain pipes at a urinal, and the chloride of lime used for disinfecting had set so hard in the pipes that a mandril could not be driven through it.

Mr. Redgrave. Mr. Gilbert R. Redgrave remarked that considerable doubt had been raised concerning the behaviour of magnesia, both alone and combined with salts of lime, in cements; but it was undeniable that magnesia was one of the best hydraulic cements. It was largely found in the well-known American cements of the Rosendale type; and, in India, a magnesian cement, prepared from an almost pure carbonate, possessed the power of solidifying in water, and became as hard as marble. The danger of its use in conjunction with lime was that the hydration of lime and of magnesia proceeded at different rates, and might thus cause imperfectly slaked magnesia to become embedded in a calcareous medium. Vicat, whose conclusions had never been controverted, was of the opinion that magnesian cements were preferable to calcareous cements for use in sea-water. Mr. Bamber stated that "theory indicates that 50 per cent. of lime would be quite sufficient" in Portland cement, and had made some experiments to carry this theory into practice. With a mixture of iron slag

Mr. Redgrave.

and lime, he (Mr. Redgrave) had made a cement, having nearly all the characteristics of Portland cement and a very high tensile strength, in which the proportion of lime was only 47 per cent.[1] Some light might be thrown on the failure of the concrete at Aberdeen by the analysis of the dry cement given by Mr. Smith (p. 63). This cement contained 13·09 per cent. of lime in combination with water and carbonic acid, which could only be the case, in well-made Portland cement, after long exposure, in thin layers, to the atmosphere, if, indeed, a good cement could ever deteriorate to this extent, by simple aeration. Adding this 13·09 to the 45·39 per cent. of caustic lime, and eliminating the water and carbonic acid, there were 58·48 parts of lime in 92·65 parts of Portland cement, or 63·1 per cent.—a dangerously high percentage of lime, only permissible in a very dense cement, burnt at an extreme temperature, and very finely ground. With reference to the action of sulphuric acid and sulphates of lime on Portland cement, some experiments of his proved that the retarded setting caused by small percentages of sulphuric acid, whether alone or in combination, was due to the "selenitic" action, first observed by the late General Scott, by means of which particles of lime became hydrated and combined with silica without change of volume. In fact, it was possible by a dose of sulphate of lime, not exceeding 2 per cent. of the whole bulk, to retard the setting of hot, overlimed Portland cements by several hours, and thus to accomplish the same effects obtained by the "purging" of the cement. There was no difficulty in making a Portland cement clinker with as much as 65 per cent. of lime; but the heat required to produce this clinker was excessive, it was most difficult to grind, and the resulting cement was of a very treacherous character. He had recently taken a sample of clinker, which had almost the appearance of gunpowder, from the mouth of one of Mr. Ransome's cylinders, fired with the pure flame of gas-producer gas. It contained over 64 per cent. of lime, was very dense, and nearly black; but he could not believe that it would pay the manufacturer to produce such a clinker. The only real test to bring out the best qualities of Portland cement was the test with sand, to which he hoped engineers would devote increasing attention. He also trusted that chemists would devise some simple plan of estimating the free and the combined lime present, and the condition of the silica, whether existing as gelatinous or insoluble, which would enable a verdict upon any sample of cement to be pronounced within a week.

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[1] Minutes of Proceedings Inst. C.E., vol. cv. p. 219.

Mr. Matthews. Mr. WILLIAM MATTHEWS (of Southampton) said that, in carrying out Clark's process of water softening, a deposit of pure chalk in an extremely finely-divided state was obtained. This precipitated chalk was crystalline, not amorphous like the chalk slurry used in the manufacture of cement. This physical difference rendered the deposit from softening works unsuitable for making whiting; and he should like to know whether Mr. Bamber saw any obstacle to its utilization for the manufacture of cement.

Mr. Brough. Mr. J. W. BROUGH said that, as resident engineer of cement works in Belgium, producing 200,000 barrels annually, he considered specifications for Portland cement should be more searching; and that, in the interest of manufacturers of good cement, the engineer should control, by an agent, the manufacture of the cement he was about to employ. In burning cement in the Dietsch kiln, great economy of fuel was obtained by having the dried slurry of uniform dimensions, thus avoiding the choking of the furnaces; and the clinker was more regularly burnt. More attention should be paid to the refractory lining of such kilns, to prevent the clinker adhering to the sides of the furnace, and thus avoid an excess of overburnt clinker. By running carefully ground slurry, containing about 40 per cent. of water, into settling tanks, decanting the water, and allowing the slip to dry, it could be readily made into bricks, and dried in hacks. By these means, when the area of the drying reservoirs was sufficient, drying kilns might be dispensed with.

Mr. Neate. Mr. PERCY J. NEATE could not agree with Mr. Bamber that air-slaking of Portland cement was a "mistaken notion." With an over-limed cement, or a cement in which free lime was present, owing to imperfect mixture or under-burning, it was the only known method of making the cement fit for use, though he believed the same effect could be instantaneously and more cheaply obtained by exposing the cement to a current of hot furnace gases and superheated steam. Good cement was deteriorated by air-slaking. Edge-runner mills had been used by Messrs. Hilton, Anderson and Co. for wet grinding, and by Formby's Cement Company, Limited, for crushing the clinker, for at least twenty years, though not with any very obvious economy. For wet milling, the presence of flints made the wash-mill the only really practicable machine. He had attempted to improve it by a mechanical arrangement for raising the harrows as the flints accumulated. He dissented from Mr. Carey's opinion that ordinary burning in a kiln tended to unduly heat the outside of the clinker, for he had never seen a piece hard outside and yellow

inside. On the other hand, one of the greatest objections to quick-burning kilns was the intimate mixture of well-burnt with under-burnt portions, necessitating increased cost of labour and constant supervision for their separation. The Dietsch kiln was the most likely novel method to supersede ordinary processes, owing to the very complete utilization of fuel heat, the continuity of the process, and the length of time allowed for the heat to penetrate to the centres of large pieces. Too much manual labour was at present required; but the objection applied still more to Joy's process, with much less prospect of its ever being lessened by mechanical appliances. Mr. Neate.

He fully endorsed Mr. Carey's view that sifted cement might be coarser than unsifted cement; and it was impossible to guarantee any particular degree of fineness by the use of a coarse-meshed sifting machine, such fineness depending mainly upon the skill of the miller, dress of stones, and quality of clinker. Nevertheless, sifters were of great value in cement works if properly handled, and if their inherent weakness was intelligently provided for. He also believed that the free use of sifters, of ample area, materially increased the output, and diminished the HP. per ton of output.

He had frequently found cement leave ordinary French burr stones at over 200° Fahrenheit, or 140° increase of temperature, due to friction between the stones and among the particles. To find the loss in HP. due to this rise of temperature, he had ascertained experimentally that the specific heat of ordinary Portland cement was about 0·155. A ton of cement, therefore, absorbed 347·2 heat-units per degree, or 48,600 units for 140° rise of temperature, equivalent to 37,500,000 foot-lbs. As millstones, $4\frac{1}{2}$ feet in diameter, at 140 revolutions per minute, could grind on the average 25 cwts. of cement per hour, 47,000,000 foot-lbs., or 23·7 HP. would be uselessly absorbed in the hour; and as the indicated HP. absorbed closely approximated to 40, the loss with millstone grinding, due to wasted heat, was 60 per cent. of the whole. He had succeeded eventually in reducing the HP., and the temperature of output, to 14 HP. per ton, and 70° respectively, with a large four-runner mill, having all its runners acting on the same inclined path in succession, and rolling at a greater mean speed than in the mill tested by Mr. Carey. He attributed the economy of this class of mill to the reduction of unnecessary friction; and further improvement was not likely to be attained without a deterioration of the quality of the grinding, because reduction of temperature as a source of economy had now reached its limit.

Mr. Thwaite. Mr. B. H. THWAITE stated that a thermic analysis showed that the ordinary cement kiln was a very imperfect contrivance of low thermic efficiency. Coke, the only suitable fuel of a porous character, was thermically, in comparison with coal at the same cost, only as twenty to thirty; whilst the uniform production and transmission of the heat in the kiln was very difficult; and as the mass of the kiln had to be heated to a high temperature, and cooled down again for each charge, the thermic loss was most serious, although the heat of the products of combustion was generally utilized for drying the slurry. Taking the specific heat of the raw materials at 0·18, and the temperature of fusion as 3,000° Fahrenheit, the thermic absorption in the treatment of a ton of the raw materials might be represented by $2,240 \times 3,000 \times 0 \cdot 18 = 1,209,600$ heat-units; whereas the actual thermic expenditure was from five to ten times as much; and therefore the highest efficiency was only about $\frac{1,209,600}{5,000,000}$, or 24 per cent. He had recently referred to a continuous process of cement burning,[1] in which the raw materials were dealt with fractionally, and in a fine state of division. It involved the employment of one or more inclined revolving cylinders, the multiple cylinder being his latest arrangement. This process, amongst other advantages, enabled hydro-carbonaceous fuel, such as semi-bituminous steam coal, to be utilized; and he considered that it would eventually, with certain structural modifications, become the regular method of fusing the raw materials. In the revolving cylinders, the cement could be produced from the dry raw materials, thus avoiding the expenditure of heat in dehydration. Cement, properly produced, should require no aeration; but otherwise it might be exposed to aerating influences in order to carbonate, or render inert, any free lime. To obtain precisely comparative tests, distilled water should be used in working up the pats, otherwise the soluble constituents of the water, such as calcium carbonate, magnesium carbonate, or calcium sulphate, might interfere with the setting, and thus give a wrong index of the character of the cement.

Mr. Watson. Mr. C. H. WATSON (of I. C. Johnson and Co.) believed that makers might much improve Portland cement with the aid of engineers; but he considered that engineers, when guarding themselves by specifying a certain tensile strain, a definite weight per bushel, and time of setting, were going beyond their province if

[1] *Engineering*, vol. lii. p. 484, 1891.

they also dictated to the maker what the composition of that cement should be, thereby reducing him to a mere machine, and dispensing with his experience. If the engineer insisted on a certain composition, he, and not the maker, must be responsible for the results. As regarded the quality of Portland cement, he would endorse a statement made by the late Mr. Grant,[1] that "the strength of Portland cement depends on the thorough amalgamation of the raw materials, the extent and degree to which they are burnt, and the greater or lesser approximation to an impulpable powder attained in grinding the clinker." It was impossible to discuss the lime question without keeping in view weight and fineness of grinding. A cement with only 50 per cent. of lime, if burnt hard enough to reach 116 lbs. per bushel, with 10 per cent. residue on a sieve of 2,500 meshes, would become an inert powder on being taken from the kiln; and the coarser the cement, the heavier would be the weight per bushel. If cement was made with 60 to 61 per cent. of lime, the maker would burn hard to obtain the desired weight; and if it was ground very fine, with a proportionate reduction in weight per bushel, the consumer would obtain a slow-setting cement of much greater value than a lightly burnt and coarse cement. The late Mr. John Grant was so convinced of the superiority of a finely-ground cement, in combination with weight, that he was prepared to add to the price in proportion to the reduced percentage of residue. If engineers acted on this sound view, it would be economical for the consumer and pay the manufacturer. He had made thousands of tons of cement ground direct from the millstones, without the intervention of sieves, to a fineness leaving 8 per cent. residue on a sieve of 5,800 meshes, 19 per cent. on one of 10,000 meshes, and 31 per cent. on one of 30,000 meshes, the weight per bushel being 112½ lbs., and the tensile strain 350 lbs. at seven days, and 480 to 500 lbs. at twenty-eight days. They were now making, at their works on the Tyne, a large proportion of finely-ground cement, and had recently erected special plant for the purpose, feeling convinced that the increased cost would be more than compensated for by the enhanced value, which was recognized by their customers. The results of twelve months' trial showed that the average tensile strength of a cement, ground to a fineness of 10 per cent. residue on a sieve of 5,800 meshes, was exactly 100 lbs. per square inch higher than that from cement with 10 per cent. residue on 2,500 meshes. This was even more marked in sand briquettes, Mr. Watson.

[1] Minutes of Proceedings Inst. C.E., vol. lxii. p. 100.

Mr. Watson. which showed a rise of 50 per cent. for the increased fineness, proving the undoubted superiority of finely-ground cement. A standard specification would retard rather than improve the manufacture, and would tend to discourage individual merit.

Mr. Bamber. Mr. H. K. G. BAMBER remarked, with reference to the experiments described on page 9, that he was present when those blocks were made and placed in the sea, and twelve months afterwards when they were examined with the results as given. He then replaced Nos. 1 and 3 blocks, where they were covered and uncovered by each tide for two years longer, and were exposed to the severe frosts of last winter. A few weeks ago they were again examined, when No. 1 block, which had been made with the full quantity of 4 gallons of water to each cubic foot of Portland cement, was found to be perfectly hard, sound, and dry throughout. No. 3 block, which had been mixed with half the above quantity of water, was found to be cracked open in several places, probably owing to its permeability and the action of the frost, and was quite soft and rotten under the hammer, and wet right through. The difference in their condition, after three years in the sea, could only be due to the difference in the quantity of water used in their manufacture. If engineers would specify a fixed quantity of water per cubic foot of cement, to be used when gauging concrete, due regard being had to the dry or moist condition and the absorptive power of the aggregate, one cause of failure in concrete work would be removed, for which the cement manufacturer frequently had to bear the blame, though really entirely owing to faulty manipulation of the concrete. Mr. Carey gave on page 42 the analyses and tensile strains of two samples of Portland cement burned in a different manner. The composition of these two cements was fairly uniform; and with sample A, containing less than 55 per cent. of lime, Mr. Carey obtained a tensile strain, after seven days, of 600 lbs. per square inch, with corresponding high results for the longer periods. He would, therefore, ask Mr. Carey, if he made the analyses of the cements himself? whether he was present when the cements were burned? and if so, how it was done? His experience during the last five years, in the manufacture of Portland cement, had been that it was practically impossible to obtain a tensile strain of even 400 lbs. per square inch with a cement containing less than 60 per cent. of lime in its composition, and that this cement must be well burned, so as to have a specific gravity, when new, of not less than 3·13. In sample A, alkalies and loss amounted to nearly 6 per cent.; but as an ordinary good sample of Portland cement rarely

contained ½ per cent. of alkalies, this great loss, pointing to inaccurate analysis, must have consisted principally of lime, which would bring the lime in sample A up to 60 per cent. With such a cement, no doubt, Mr. Carey would obtain a tensile strain of 400 lbs. per square inch, or perhaps results recorded under sample B, but not the results given for sample A with the stated proportion of lime. The test of weight per bushel was entirely misleading, and did not show with any certainty that a cement had been well burned. He had found by experiments that although the specific gravity was not affected by the fineness of grinding, and was not liable to the variations of the weight per bushel, it decreased with the age of the cement, as shown by the following Table:— Mr. Bamber.

Period.	Specific Gravity.					
	1	2	3	4	5	6
When new . . .	3·131	3·129	3·133	3·128	3·127	3·130
After fourteen days .	3·122	3·122	3·126	3·121	3·123	3·126
After one month . .	3·112	3·106	3·113	3·070	3·102	3·100
After four months .	3·022	2·969	3·001	2·994	3·006	3·010
Loss in four months .	0·109	0·160	0·132	0·134	0·121	0·120

The cement should therefore be specified to be of a certain specific gravity at any time within one month after its manufacture, and the standard should be fixed at not less than 3·1. As, however, the specific gravity of a cement continued to decrease after one month, if a cement should be found to have a lower specific gravity than 3·1, it should not be condemned, provided satisfactory evidence could be given that the lower specific gravity was caused by age, and not by the cement having been insufficiently burned.

Mr. W. G. Margetts desired to make a few observations regarding hot-water tests for Portland cement. Mr. Le Chatelier had said:— Mr. Margetts.

"It is at first sight strange that tests of this character should be adopted for a material which is rarely used under like conditions. To understand this, it is necessary to remember that cements, when actually incorporated in the work, suffer gradual change, from the moment of setting until they are destroyed. Such disintegrating agencies need time for their action to become perceptible, so that no successful attempt to gauge the quality of the cement, by imitating the natural conditions to which it is subjected, is possible in any reasonable

Mr. Margetts. period. There is, at present, only one way of determining whether the judgment passed on a cement, by any system of testing, is sound, and that consists in waiting half a century to see how the work stands."[1]

Any method, therefore, which would accelerate the discovery of unsoundness was of the highest importance; and his firm, the West Kent Company, since early in the year, had made hot-water trials part of their daily tests of their cement, with very satisfactory results. The average tensile strain with cement briquettes of 1 square inch section, in cold water at seven days, was 494 lbs., and after twenty-four hours' exposure in air and forty-eight hours' immersion in boiling water, 442 lbs., and with briquettes made of 3 of sand and 1 of cement, after seven days in cold water, was 153 lbs., and after three days in boiling water, 130 lbs. One-inch briquettes, after boiling for fifty days, bore over 600 lbs.; and pats put into boiling water a few hours after setting, were perfectly sound after boiling several days. No signs of disintegration appeared in any of the above tests. Ten other cements of various makes, when put into boiling water, disintegrated more or less, some simply turning to mud; and in no instance could they be submitted to the testing machine, though good results were obtained by the usual cold-water tests. It had, hitherto, been deemed a sufficient safeguard, in addition to the usual cold-water tests, to analyse the cement with a view of ascertaining the quantity of lime in its composition; but his firm had found, from long experience, that this idea was fallacious, and that the soundness of a cement to a very large extent depended upon its perfect combination. They had proved that a cement, having as little as 56 per cent. of lime, might not be perfectly combined; while, as Mr. Le Chatelier had shown, a cement might contain as much as 65 per cent. of lime, and yet be in perfect combination. In the accompanying record of tests of two samples of cement[2] furnishing almost

[1] "Bulletin de la Société d'Encouragement pour l'Industrie Nationale," 1890, p. 560.

[2] No. 1 Cement.

Moisture	0·00	Magnesia	0·63
Carbonate of lime	60·67	Sulphuric anhydride	0·36
Silica	24·86	Carbonic "	0·47
Oxide of iron and alumina	12·28	Alkalies	0·73
Total			100·00

Specific gravity	3·11
	Per Cent.
Residue on a 76-inch sieve	14·00
" 50-inch sieve	7·00
" 30-inch sieve	0·72

Average tensile strain, on 1 square inch section, after six days' immersion in cold

identical analyses, while sample No. 1 stood the entire tests, No. 2 disintegrated at the end of three hours, thereby demonstrating an imperfect combination. These results could only have been obtained by means of the hot-water tests, and illustrated the enormous importance of these tests. The uniformly good results indicated above were believed to be due to the greater care exercised in the mixing of the raw materials in a liquid state, and, while in this condition, passing the mixture through centrifugal sieves working at a high speed, thereby eliminating any minute particles of chalk which might not have been dissolved in the previous process, and which would probably remain uncombined and become free lime. Inattention to these primary details of the manufacture was the cause of the faulty state of many cements. All the tests were made with boiling water, as it was found easier to keep at that point than 176° mentioned in the French Paper. Mr. Margetts.

Mr. Bindon B. Stoney would ask Mr. Bamber if he agreed with the opinion, held by some chemists, that the reactions which caused cement to set, and eventually harden, involved the liberation of a considerable quantity of calcium hydrate, this liberated calcium hydrate being additional to any free lime that might happen to be in the cement before mixing with water. From twenty to thirty years ago cement had invariably a much larger proportion of coarse particles than modern cement, and he had used considerable Mr. Stoney.

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water, 496 lbs. Average tensile strain, on 1 square inch section, after twenty-four hours exposed to the air, and forty-eight hours immersed in water kept at the boiling point, 418 lbs. The briquettes showed no signs whatever of disintegration. Pats put into boiling water three hours after setting were also perfectly sound.

No. 2 Cement.

Moisture	0·00	Magnesia	0·58
Carbonate of lime	60·47	Sulphuric anhydride	0·30
Silica	24·93	Carbonic „	0·52
Oxide of iron and alumina	12·42	Alkalies	0·78
Total	100·00		

Specific gravity	3·118
	Per Cent.
Residue on a 76-inch sieve	24·00
„ 50-inch sieve	14·00
„ 30-inch sieve	1·00

Average tensile strain, on 1 square inch section, at seven days (six days' immersion in cold water), 390 lbs. Briquettes exposed to the air for twenty-four hours, and then immersed in boiling water, disintegrated at the expiration of three hours, rendering any further tests impossible.

Mr. Stoney. quantities of this coarse cement, but neither in the briquettes nor in the concrete had the coarser particles shown signs of expanding or disrupting the cement; and he would ask Mr. Bamber if there was any difference in the manufacture now that would explain the view put forth in his Paper, that these coarse particles absorbed water "after the principal part had hardened, causing internal expansion and disruption of the cement, in the same way as lumps of lime become disintegrated." The coarser particles were the most highly calcined parts of the cement, and probably contained little or no free lime.

Mr. Neate. Mr. CHARLES NEATE observed that there appeared to be no example of Roman cement having failed as Portland cement had done in one or two instances, and this was probably owing chiefly to the smaller percentage of lime in Roman cement, viz., about 40 per cent. against 60 per cent. in Portland cement. Some years ago he had observed the concrete used for moles and other marine works at and near Naples, which consisted of 1 measure of white lime and 2 of pozzuolana, mixed with 3 of volcanic scoria. The mixture was left in the open air for several days, sometimes a fortnight, before being used, and it was then deposited in the water between two rows of sheet piling, which formed the front and back faces of the structure. The piling was rough and not close-jointed, and the concrete was tipped in small quantities out of baskets; but, though apparently hard when used, it became sufficiently plastic under water to consolidate into a compact mass. On the sea face, however, the wall was usually protected by a rubble mound; but the mole itself consisted wholly of concrete. The Neapolitans had followed this mode of construction for generations, and had full confidence in it. Mr. Vicat gave the following analysis by Dr. Berthier of pozzuolana:—

Silica	44·5	Magnesia	4·7
Alumina	15·0	Soda	4·0
Oxide of iron	12·0	Potassium	1·4
Lime	8·8	Water	9·2
		Total	99·6

Taking these figures, and assuming the above-mentioned proportions of 1 of lime to 2 of pozzuolana, the percentage of lime in this mortar would not differ greatly from that of Roman cement, as shown by the following Table, to which the constituents of Portland cement were added for comparison:—

Mr. Neate.

Constituents.	Portland Cement.	Roman Cement.	Naples Mortar.
	By Mr. Bamber.	*By Mr. Smith.*	
Silica	23·32	23·63	29·6
Alumina and oxide of iron	12·13	22·20	10·0 8·0
Lime	61·56	41·24	39·2
Magnesia	1·07	0·63	3·2
Sulphuric acid	1·28	2·23	..
Carbonic acid	0·30	10·07 and water	..
Soda	..	..	2·7
Potassium	..	..	0·9
Organic matter	0·34	..	..
Water	..	..	6·1
	100·00	100·00	99·7

Mr. Geo. L. Fuller said that he had latterly carried out a considerable amount of concrete sea walling, and always tested every consignment of cement by making briquettes both with fresh water and sea-water, but had not detected any material difference in the tensile strength of the two samples. Nevertheless, the briquettes made with sea-water exhibited a considerable efflorescence, which was entirely absent in briquettes made with, and immersed in fresh water. He sent a specimen of the efflorescence scraped off three briquettes, of 1-inch section, made of a Rugby cement he was at present using, mixed with, and immersed in sea-water for six days, at which period his tests were applied. Mr. Fuller.

Mr. H. N. Draper observed that Portland cement might vary in chemical constitution and in physical state, and there was little accord as to the conditions which insured success. Some sort of theory, therefore, as to its constitution and setting was indispensable. Mere analysis of the cement was not of itself a certain guide to its efficiency. He had taken, without selection, five analyses, and considering only constituents which played an active part in the setting, he found that the lime, silica, and alumina formed, on the average, nearly 90 per cent. of the weight of the cement, namely, lime $61 \cdot 02 +$ silica $20 \cdot 29 +$ alumina $8 \cdot 25 = 89 \cdot 56$ per cent. The most recent view of the constitution of Portland cement, by Le Chatelier, was that its potentially active components were tricalcic silicate (SiO_2, 3 CaO), and tricalcic aluminate (Al_2O_3, 3 CaO). The nearest approach which could be made, from the proportions of actual cement, to a rational formula in accord with this theory, was 3 (SiO_2, 3 CaO), Al_2O_3, 3 CaO, which would agree with an analysis of CaO $63 \cdot 08 + SiO_2\ 16 \cdot 89 + Al_2O_3\ 9 \cdot 57 = 89 \cdot 54$ per cent. Here the lime was $2 \cdot 06$ per cent. higher, the alumina $1 \cdot 32$ per cent. Mr. Draper.

Mr. Draper. higher, and the silica 3·40 per cent. lower than the actual analysis; but the figures were near enough to suggest that the formula was probably correct. Mr. Bamber observed that "theory indicates that 50 per cent. of lime would be sufficient," but did not say what theory; nor did the results of his own experiments with this proportion support it. If the view he (Mr. Draper) advanced was well founded, a properly burned cement, containing 61 per cent. of lime, did not contain any free lime. "Free lime" had long been the *bête noire* of users of cement. It was natural to suppose that Portland cement, which was strongly alkaline to test paper, and which, on being washed with water, gave a solution containing calcium hydrate, should contain lime in a free state. But when the change that occurs on mixing water with cement was rightly understood, this difficulty vanished. The reaction affecting the tricalcic silicate only, was $2\ (SiO_2,\ 3\ CaO) + \text{water} = 2\ (SiO_2,\ CaO)\ 5\ H_2O + 4\ CaH_2O_2$, so that four molecules of calcium hydrate were set free. One of these at the same time combined with water and the tricalcic aluminate, giving $Al_2O_3,\ 3\ CaO + CaH_2O_2 + \text{water} = Al_2O_3,\ 4\ CaO,\ 12\ H_2O$; and therefore, in the theoretical cement of his formula, there were, on moistening with water, and even after setting, five unused molecules of calcium hydrate, though all the lime in the original cement was in a state of combination. A recent experiment of his own strikingly supported this view: 8 grammes of fine cement were agitated for some hours with a litre of distilled water, at the same time that 10 grammes of a briquette, originally containing 80 per cent. of the same cement, and made nearly six months previously, were similarly treated. The lime was precipitated as oxalate from the filtered solution, and weighed as carbonate, giving 0·235 gramme of calcium carbonate obtained from the original cement, and 0·253 gramme from the hydrated cement. The calcium hydrate thus set free was an important factor in the efficiency of the cement, because, as pointed out by Mr. Bamber, it gradually combined with the siliceous sand of concrete, and increased its strength. It also absorbed carbonic acid, forming the protective film of carbonate noted by Mr. Smith. Thus the chemical conditions of ordinary lime mortar were superadded to the more immediate consequences of the hydration of the cement. If the proportions of lime and alumina, indicated by the analyses cited, were those of a typically good cement, the cement employed at the Aberdeen graving dock could not, according to the analysis (p. 63), be considered good. Not only was the alumina very high (13·2 per cent.), but the whole of the available lime (oxide and hydrate) amounted only to 52·39 per cent., and

Mr. Draper.

there was 8·18 per cent. of absolutely inert calcium carbonate. If Le Chatelier's theory as to the composition and setting of cement was true, and the cement used was such as he had indicated, aeration should be unnecessary, and might be injurious; for with no free lime, the conversion of any part of the lime into carbonate could only reduce the cement's tensile strength. As to the quantity of water to be used, there seemed to be a concensus of opinion among practical men that about 20 per cent. by weight was amply sufficient, which was the quantity recommended by Mr. Bamber; and Mr. Carey, in his experiment with neat cement (Appendix VI), used 18·7 per cent. If 89 per cent. of the cement consisted of tricalcic silicate and tricalcic aluminate, in the proportions indicated by his formula, and the hydration reactions of Le Chatelier were correct, no less than 41 pèr cent. of water would be required for complete hydration. A good cement would absorb and set in a few hours with this proportion; but if, in practice, it was found to be twice as much as that which gave the best results, there could only be two explanations. Either there were other hydrates than those of Le Chatelier, containing less water, or the whole of the lime, silica, and alumina of the cement did not exist as tribasic silicate and aluminate. The truth probably lay between the two alternatives; but experiments, in which the cement was in the finest available state of division, the quantity of water as great as the cement could absorb, and the test for tensile strength made, not after an interval of days, but of months, were very desirable. With the present standard of fineness, and the present limit of time, it was not possible to determine the best proportion of water. That the absorption of water was very gradual was shown by Mr. Carey's experiments on the protracted immersion of a briquette of neat cement in sea-water (Appendix VI), where an increase in weight of 12 per cent. occurred in four months. Mr. Carey attributed the vitreous "skin," which he considered so desirable on the surface of finished work, to the solution of alumina silicates; but as there was no evidence that these silicates were soluble, it was much more likely that this glassy coating was due to silicates, which, owing to their low specific gravity, rose to the surface in the highest state of mechanical division, and became at once completely hydrated. The ideal cement of his conception would be all "skin." Average Portland cement in England did not contain much magnesia; but in America, the Rosendale cements, which Gillmore stated were "our chief and best reliance in the United States," were made from a limestone containing not less than one part of magnesium carbonate, and sometimes two, to two of calcium

Mr. Draper. carbonate. Mr. Bamber, following Le Chatelier, thought that a cement containing magnesia might become disintegrated, because magnesia was more slowly hydrated than lime. But, even if in a silicate (or aluminate) containing two bases, the hydration of one of these could possibly precede that of the other, the experiments of Mr. Jones, cited by Mr. Smith, showed that there was no foundation for this conjecture. If, on the other hand, the question simply was whether magnesia in cement was only inert, it was largely answered by Gillmore's opinion just quoted, and by Vicat, who found that cements containing magnesia resisted the action of sea-water better than those which contained lime only. Mr. Smith's objections to magnesia because the tendency of its solutions, "on a glass slide, is to roll off like quicksilver," and because its precipitates are amorphous, and his conclusion that "probably the adhesive property of Portland cement is due simply to the restoration of the water of crystallization to the lime and alumina," suggested the remark that chemical questions might advantageously be left to chemists. If, as was unquestionable, Portland cement mixed with water contained lime as hydrate, a briquette of theoretical cement, having his formula, gauged with the theoretical quantity of water, would contain nearly 27 per cent. by weight of calcium hydrate. If this briquette was immersed, for an indefinite period, in a magnesium solution, each molecule of calcium hydrate accessible to the solution might be replaced by a molecule of magnesium hydrate. But for this deposition of magnesia by the immersion of such a briquette in sea-water, which, on an average, contained 0·29 per cent. of magnesium expressed as hydrate, it would be necessary to suppose that seventy-three times its weight of sea-water had access to it, throughout its mass, at an early period. Even then, there was no evidence that the action of the magnesia so deposited would be injurious to the continuity of the cement. The calcium hydrate set free in the setting process could only be effective either by combining, in the case of cement alone, with carbonic acid, or, in the case of concrete, by combination with free silica. He felt no doubt that any calcium hydrate, not carbonated or silicated, and which would be washed out in fresh water, would be usefully employed in forming an interstitial filling of a much more insoluble base. An opinion seemed to prevail that, because more magnesia was found in concrete which had been deteriorated by the action of sea-water than existed in the original cement, the magnesia was the cause of the trouble. This was evident from Mr. Smith's quotation from Mr. Messent's citation of the view of

Messrs. Brazier and Pattinson, and his deduction that an addition of 4 per cent. of magnesia to the cement was required to cause complete softening of the concrete. The theory of Professor Brazier appeared to embody the accepted view of the action of sea-water; namely, first, that the magnesium hydrate, which, by double decomposition, replaced the calcium hydrate of the cement, occupied more space, and "caused swelling of the concrete"; and, secondly, that hydrated sulphate of lime, formed at the same time, played the same part. As to the first, it had no basis of fact to support it. He found by experiment, that the specific gravity of freshly formed calcium hydrate was 2·12, and of freshly formed magnesium hydrate, in its bulkiest form, 1·65; and so far the figures favoured the theory. The molecular weight, however, of calcium hydrate was 74, and of magnesium hydrate only 58; and, therefore, the space occupied by one molecule of magnesium hydrate was to that of one molecule of calcium hydrate, as 35·14 to 34·8. But the magnesia was probably deposited in a much denser form, as the specific gravity of its natural hydrate, brucite, was 2·35. As regarded the action of calcium hydrate, it had been stated that crystals of this salt had been found in ordinary mortar which had been exposed to sea-water for years, and therefore such crystallization might possibly occur in permeable concrete. As, however, 1,000 parts of distilled water dissolved 2·54 parts of calcium sulphate, and it was much more soluble in water containing sodium chloride, and as 1,000 parts of sea-water only contained 1·4 parts of the salt, and were, therefore, capable of dissolving at least 1·14 parts more, it was scarcely reasonable to suppose that such crystallization took place. If it did, its injurious action could not be due, as Mr. Smith suggested, to the relatively "great bulk" of the sulphate, because, in sea-water, the sulphuric radicle in the magnesium sulphate bore to the chlorine in the magnesium chloride only the proportion of 1·75 to 3; and the magnesium chloride being a still more active factor than the sulphate (p. 64), the quantity of calcium sulphate deposited could not be large enough to act injuriously simply on account of its greater volume. If crystals of calcium sulphate should ever be found in deteriorated concrete, the only action which could be ascribed to them must be the disruptive force of the process of crystallization. The conclusion at which he had arrived, based entirely on chemical considerations, was, that if a good cement, as finely ground as possible, was mixed with sufficient water to completely hydrate it, and adequate time allowed before immersion to effect this hydration, there was little Mr. Draper.

Mr. Draper. to fear from the action of sea-water on properly proportioned concrete. Proof in support of this conclusion was furnished by the work done in the Port of Dublin under Dr. Bindon B. Stoney, much of which had borne a time test of from ten to twenty-five years. As to the causes of the Aberdeen disaster, he would ask whether a good cement was employed, whether enough water was used, and sufficient time given.

Mr. Reid. Mr. W. F. Reid observed that Portland cement could not strictly be said to be made from a mixture of clay and chalk, for Aspdin, the inventor of Portland cement, made it from limestone; and the bulk of the Portland cement made in Germany was not made with chalk, and some of it was made with other materials than clay. He had designed and erected several factories, where either one or both of the above-mentioned materials were dispensed with, and excellent Portland cement produced. In the analysis of clay given by Mr. Bamber, the alkalies were not mentioned, whereas all the Thames and Medway clays contained alkalies; and tests made with several hundred clays from all quarters of the globe, had led him to the conclusion that no clay free from alkalies would produce a good Portland cement. It would be interesting to learn upon what evidence the statement (page 5) that "the lime in concrete gradually combines chemically with quartz sand" was based. Mr. Spiller found the reverse to be the case,[1] and his researches had been corroborated by several German analysts.[2] In the old Roman mortars which he investigated, the whole of the lime had been reconverted into carbonate without acting on the sand. The specific gravity of cement was undoubtedly a better guide than the weight per bushel; but precautions were necessary to ascertain it accurately. Some of the liquids used, especially turpentine, contained considerable quantities of water, and they should be first shaken up with some fresh Portland cement to absorb the water. The statement that "the larger particles absorbing water after the setting of the finer ones would cause internal expansion and the disruption of the cement" (page 6) first appeared, he believed, in 1869, but he could never find any evidence in support of it, and would be obliged if Mr. Bamber could afford some. He had been unable to produce such expansion experimentally, and did not think it took place with good cement.

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[1] J. Spiller, Deutsche Industrie-Zeitung, 1868, p. 397.

[2] H. Latzko, Chemisches Centralblatt, 1859, p. 818; A. Bauer, Dingler's Polytechnisches Journal, vol. 150, p. 62; A. Vogel, Dingler's Polytechnisches Journal, vol. 147, p. 190.

Mr. Reid.

He had seen a cargo of Portland cement clinker, which had been under water for five years, and there had been no appreciable change externally in the lumps of clinker. The claim (page 6), of priority in making cement from iron slag was incorrect, for J. J. Bodmer was the first to make cement from this material in this country, and described the process in his patent specification, No. 1970, of July 31st, 1866. Egleston mentioned the same subject,[1] but the Germans claimed to have originated this industry; and it appeared that Emil Langen, of Siegburg, was the first to use slag as a hydraulic substance;[2] Lürmann, of Osnabrück, used slag and lime previous to 1870; and the Prinz zu Schönaich-Carolath had described the manufacture of a hydraulic cement from slaked lime and slags from zinc smelting furnaces.[3] As to the proportions of the raw ingredients (page 8), when the percentage of lime in undoubtedly good cements differed 6 to 8 per cent., there must be conditions in some cases which did not quite agree with any existing theories. The remarks on cement made from dolomite (pp. 10, 14, and 28) could only refer to cements burnt at a high temperature, for when burnt at a low temperature, magnesia, or limestone containing a considerable proportion of it, hydrated rapidly and yielded an excellent hydraulic cement, which was much less acted upon by sea-water than Portland cement. The French official rules provided for supervision during the manufacture; and he was informed that, since this regulation had been in force, disputes as to the quality of the cement supplied to Government had almost ceased. Mr. Carey rightly condemned clays containing a large proportion of sand (p. 12); but in none of the analyses of clays was the percentage of sand mentioned, and it was impossible to judge of the quality of a clay for cement making from the proportion of silica alone; the form in which that silica was present was of the greatest importance. The iron in cement was stated (p. 13) to be in combination with alumina; but it had hitherto been regarded as combined with the lime, and any new facts on this subject would possess great theoretical and practical interest. Iron pyrites was not present in cement (p. 13), being decomposed in the burning. Neither Mr. Bamber nor Mr. Carey had referred to the production of Portland cement from other materials than chalk and clay, which in this country, and especially abroad, was rapidly increasing. He could affirm, from

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[1] Proceedings American Inst. Mining Engineers, 1872.

[2] Stahl und Eisen, 1890, p. 625.

[3] Zeitschrift für Berg- und Hüttenwesen, 1866, p. 1062.

Mr. Reid. many years' experience, that better and more reliable Portland cement could be made from compact limestones of suitable composition than from either white or grey chalk; and in most countries there was an abundance of silicate of alumina in even more suitable forms than alluvial clays. The mechanical treatment must be suited to the material; but this was easy with modern appliances. The Portland cement industry had been maintained on the Thames and Medway mainly owing to the cheap supply of London coke. He had examined samples of clinker and cement from one of the factories near Cambridge (p. 14), and came to the conclusion that no good cement could be made by burning the chalk marl as dug.

Portland cement in an extremely fine powder was completely decomposed by water; and the finest sieve was a coarse test scientifically compared with the water test, which was serviceable in testing the fineness of powder which had passed through the finest silk sieves. In testing the raw mixture, a modified form of Lunge's new nitrometer, or Japp's volumeter was preferable to Dietrich's or Scheibler's calcimeter, as the influence of the variations of barometer and thermometer on the volume of the carbonic acid evolved was eliminated. In Germany the manufacturers themselves first introduced standard tests; and the average quality of German Portland cement was now far better than the English. Standard rules had been adopted by America, in 1884; Germany and Switzerland, in 1887; and Austria, in 1888. In the proposed specification (p. 36) he would suggest omitting the words "or other approved section," because the strength per square inch was so dependent on the section. Salt should not be used to avoid freezing (p. 27) where the concrete was not permanently wet; for on investigating a failure of concrete in a dry situation, he found that an excellent cement had been completely disintegrated through the action of salt added to it. The researches of R. Dyckerhoff[1] showed that any Portland cement containing more than 4 per cent. of magnesia was unreliable. With regard to the action of sea-water upon cement, the numerous researches published within the last few years were at variance with Mr. Carey's theory that "the precipitation of magnesium salts is merely the deposition, without active chemical change and consequent change of volume, of bodies which already exist there in solution" (p. 32). The magnesium salts in sea-water and the calcium salts of the cement underwent a double decomposition, 40

[1] Verhandlungen des Vereins deutscher Cement-Fabrikanten, 1887–1890.

Mr. Reid.

parts by weight of calcium being replaced by 24 parts of magnesium with a corresponding diminution in volume. Mr. Smith attributed the large expansion of the concrete at Aberdeen to "a deposit of magnesia and hydrated sulphate of lime" (p. 51), whereas the chemical substitution of magnesia for lime caused a diminution in volume. The expansion by hydration of the sulphate of lime could only be due to the amount of this salt in the original cement, because all the salts in sea-water were already fully hydrated. The percentage of sulphuric acid originally present was 0·82; and, assuming the whole of this to be combined with lime and to be subsequently hydrated, the consequent expansion in the large bulk of porous concrete would be insignificant. In the analyses of Professor Brazier, the substances were grouped in so fanciful a manner that they would require recalculation to give an accurate idea of the changes that had taken place. Thus, in the decomposed concrete from the south breakwater, the whole of the lime (p. 63) was given as carbonate, leaving 4·89 per cent. of the sulphuric acid either in the free state or combined with magnesia. The sulphuric acid could hardly be free, and if present as sulphate of magnesia, it must, according to the theory based upon these analyses, have re-acted with the lime, otherwise, being soluble, it would have been washed out by the first tide. The formation of a compound of lime with carbonic acid could not be the cause of expansion, because this compound was formed even more readily in fresh water than in salt-water, while the failures described appeared to be confined to salt-water. He hoped that further experiments might throw some light upon this important subject. The addition of some crushed limestone to concretes of low strength considerably retarded, and in some cases appeared to prevent the action of sea-water upon them. In some situations this simple means might be adopted for greater security; but absolute security could only be secured by using a sufficient proportion of cement. Mr. Smith stated (p. 53) that "hydrate of magnesia, or mixtures of hydrate of magnesia with lime or carbonate of lime, are not cementitious substances," which was in direct contradiction to the results obtained by others, especially by C. Calvert, who proved many years ago that hydrate of magnesia was a valuable cement. The conclusion appeared to be solely drawn from the behaviour of the magnesia precipitated from sea-water, which could hardly be expected to act as a cement, unless previously burnt at a suitable temperature. The hydraulic properties of magnesia, including the rate at which it absorbed water, were entirely dependent upon the temperature at which it was calcined. Heated

Mr. Reid. to the temperature at which Portland cement was burnt, magnesia absorbed water very slowly, and appeared devoid of hydraulic properties. Mr. Smith remarked (p. 54) that the temperature to which clinker was raised in the process of grinding made the "dead-burnt gypsum" in it pass into the state of ordinary gypsum. Hitherto it had been considered that over-burnt gypsum required rehydrating, and subsequent reheating at a moderate temperature, before it acquired the property of setting, and this was confirmed by the quotation given by Mr. Smith. The carbonic acid in sea-water, far from destroying the cement (p. 55), was, in his opinion, the most important agent in preserving it. Analyses of old Roman and Phœnician mortars showed that all the lime they contained had been reconverted into carbonate, with the result that such mortars were now as hard as the limestone from which the lime was derived, and as little liable to deterioration in salt-water or fresh water. The cement should be apportioned to the vacant space existing in the ballast, which could be ascertained by measuring the quantity of water taken up by a given volume of the ballast. Moreover, only about 50 per cent. of any ordinary English cement possessed any cementitious value for the first few years, so that a concrete of 1 to 8 was practically a 1 to 16 mixture. In making the harbour of the North Sea Canal about ten years ago, a concrete composed of 1 Portland cement, 3 sand, and 6 gravel, was used, which failed in exactly the same way as at Aberdeen, and was replaced with a material consisting of 2 Portland cement, 3 sand, and 5 gravel, which had hitherto stood well. He differed from Mr. Smith as to the cause of the cracks in monolithic concrete structures (p. 60), which were attributed by some persons to the expansion of free lime in the cement. Expansion, however, whatever its cause, would produce a heaving of the mass; whilst cracks must be due to contraction. Neat Portland cement invariably cracked in dry situations, and this tendency could only be reduced, not entirely removed, by a considerable admixture of other materials. The experiments of Schumann[1] showed that the contraction of neat Portland cement was 0·04 per cent. within the first month, and continued for several years. Most of the phenomena observed, and especially microscopic investigation, favoured the "colloid" theory of the setting of cement.

Mr. Feret. Mr. R. Feret observed, that being the head of the laboratory at Boulogne, controlling the manufacture of cements supplied

[1] Verhandlungen des Vereins deutscher Cement-Fabrikanten, 1889.

by various firms to the French government harbour works, Mr. Feret.
and for making investigations on cements and the action of sea-water upon them, he offered the following remarks. Mr. Bamber's view, that in mortar made with quartz sand some of the lime in the cement combined chemically with it, might be incorrect; for he had often verified that the silica in quartz is absolutely inert by examining thin slices, cut from 3 to 1 Portland cement briquettes, under a polarizing microscope. Though in some cases the mortar had been made several years previously, the angles of the grains of the quartz sand remained perfectly intact. As regarded the fineness of grinding, he considered that Mr. Bamber was mistaken in supposing that a good cement expanded in setting, and that therefore the later setting of the coarse particles might lead to disruption; and he was opinion that Mr. Carey's view, that the coarse particles were equivalent to so much inert sand, was more correct. From a number of experiments he had made, most of which he had described in a Paper[1] published in 1890, it appeared that the coarse grains were quite inert during the earlier period of setting, but that if not too coarse they underwent eventually the chemical change, though almost wholly on the surface only. Slices of old mortars exhibited, under the microscope, unchanged crystals of silicate of lime in the interior of the grains of cement. From a set of experiments given below,[2] not described in the above-mentioned Paper, carried out with the

[1] Annales des Ponts et Chaussées, 6th Series, vol. xix. p. 346.

[2] Tests of Cement and Mortar Briquettes made with Cements of three different Qualities of Fineness.

—	Fine Powder.	Average-sized.	Coarse.
	Per Cent.	Per Cent.	Per Cent.
Cement A.	50 cement.	31 cement.	19 cement.
Cement B.	50 cement.	31 cement.	19 sand.
Cement C	50 cement.	31 sand.	19 ,,

The sand replacing a portion of the cement in B and C, was quartz sand, of equal volume and coarseness as the cement it was substituted for.

Fine cement passed through a sieve of 32,300 meshes to the square inch.

Average-sized cement passed through a sieve of 5,800 meshes to the square inch, but was retained by a sieve of 32,300 meshes to the square inch.

Coarse cement was retained by a sieve of 5,800 meshes to the square inch. The breaking strains given are the mean results obtained with six briquettes of

Mr. Feret. object of determining the size of grains beyond which cement must be reckoned inert, it appeared that, except in the experiments with neat cement, the substitution of sand for the coarse grains of cement retained by a sieve of 5,800 meshes to the square inch, did not appreciably modify the strength; most of the breaking strains being, indeed, slightly higher where sand took the place of the coarse grains of cement. Where sand was substituted also for the average-sized grains of cement, which passed through a sieve of 5,800 meshes, but were retained by a sieve of 32,300 meshes, the breaking strains, in some cases, were still slightly higher than with the unsifted cement, but in other cases decidedly lower, especially under compression. The average-sized grains of cement, accordingly, appeared to possess a certain energy; whilst the almost inert coarse grains should be eliminated as far as practicable. The large increase, however, in the price of a very finely-ground cement would prohibit the reduction of coarse grains below a certain proportion; and he had given a calculation, in his published Paper, as to the fineness of grinding which was most economical to the consumer.

0·775 square inch section for tension, and with two cubes, having sides of 7·75 square inches, for compression.

Fineness of Cement used.	Neat Cement.		Mortars composed of 1 of Cement to 3 of Standard Quartz-Sand by Weight Compressed.		Mortars composed of 1 of Cement to 3 of fine Gravel by Weight, mixed with a Trowel to a Plastic Consistency.														
	Mixed with, and immersed in Sea-Water.		Mixed with, and immersed in Sea-Water.		Mixed with, and immersed in Sea-Water.					Mixed with, and immersed in Fresh Water					Mixed with Fresh Water, and kept in Air.				
	Tension.		Tension.		Tension.			Compression.		Tension.			Compression.		Tension.			Compression.	
	4 Weeks.	1 Year.	4 Weeks.	1 Year.	4 Weeks.	12 Weeks.	1 Year.	12 Weeks.	1 Year.	4 Weeks.	12 Weeks.	1 Year.	12 Weeks.	1 Year.	4 Weeks.	12 Weeks.	1 Year.	12 Weeks.	1 Year.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
A	422	736	149	275	95	115	179	327	540	71	88	146	469	731	70	77	173	426	838
B	383	657	152	294	97	115	207	398	525	89	84	155	497	724	119	136	258	454	859
C	310	447	128	216	94	122	204	256	398	67	78	142	291	426	87	92	195	327	454

Mr. Feret.

With reference to the failures at Aberdeen, various experiments had been carried on for several years in laboratories in France, to investigate the action of sea-water on mortars, and it had been fairly established that magnesium sulphate was the only injurious substance in sea-water. At Boulogne, sea-water was made to percolate through blocks of mortar, and the results with mortars of various compositions were compared. Glass tubes were fixed in cubes of mortar of 21·6 cubic inches, penetrating to their centre, and were connected with a pipe supplying sea-water under a pressure of about $6\frac{1}{2}$ feet; and the cubes were placed in glasses in which the percolating water was collected and measured. These experiments exhibited clearly the difference, already noted by various observers, between the permeability of mortars or their capacity for allowing water to pass through them, and their porosity or their power or retaining water in their pores. Generally, the most porous mortars were the least permeable, and *vice versâ*. Coarse sands produced mortars which, having few, but comparatively large interstices, allowed water to percolate freely through them. Mortars, on the contrary, made with fine sands contained numerous small pores into which the water penetrated, but was retained by capillary attraction, and consequently, whilst exposing a much greater wetted surface than mortars made with coarse sands, allowed little water to pass through them. The results of passing sea-water through permeable, and through porous mortars were very different. With the former, an abundant white efflorescence was quickly deposited, forming sometimes veritable stalactites, due to the decomposition of the calcium silicate of the cement into a product less rich in lime (the crystallization of which effected the setting of the cement), and into lime which, carried along by the water, was converted into carbonate by contact with the air, or with the sea-water, which was always more or less charged with carbonic acid. No alarm need be felt at the appearance of this efflorescence, for the mortars on which they were formed could resist the decomposing action of sea-water for numbers of years; and, moreover, their permeability rapidly decreased. In porous mortars the efflorescence was much less abundant, and never attained any great thickness. After periods, however, of varying duration, depending upon the quality of the cement and the manufacture of the mortar, thin white hair cracks appeared on the surface, which very soon enlarged, changing into fissures which opened more and more till pieces fell off and laid bare a soft pulp of decomposed mortar inside the cube, from which a white flocculent precipitate separated when the pulp was shaken

Mr. Feret. in water, which precipitate had the following composition by weight:—

Silica	15·15	Sulphuric acid	7·25
Alumina	4·90	Carbonic acid	11·00
Sesquioxide of iron	1·15	Water	30·70
Lime	22·60	Chlorine	0·45
Magnesia	5·85	Alkalies and losses	0·95
Total			100·00

Although these observations seemed to indicate that mortars through which water passed freely were less dangerous than the finely-divided porous mortars, which were less subject to percolation, but exposed a greater surface to chemical action, it evidently would be unwise to use such mortars; and the aim should be to make mortars neither too porous nor too permeable. Numerous experiments convinced him that this object could be attained, without unduly augmenting the proportion of cement, by selecting a suitable sand, the best mortars being those containing about 2 parts by weight of coarse gravel to 1 part of a mixture of cement and fine sand, which were improved in proportion as the cement was increased in relation to the fine sand in the mixture.

Both Mr. Bamber and Mr. Carey stated that a too small proportion of water in mixing was injurious to the mortar; but it would be necessary to define precisely the best consistency to aim at, for the proportion of water corresponding to a certain consistency varied considerably with the richness of the mortar in cement, and the size of the sand. The Table on the next page, giving the results of experiments made at Boulogne, clearly indicated that for each mixture of a definite cement and a definite sand, there was a certain proportion of water which imparted a greater strength to the mortar than any smaller or larger proportion. In the Table, n represented, for each of the three mixtures experimented upon, the proportion of water which gave the mortar the best plastic consistency; whilst the maximum strength corresponded to a rather drier consistency. As regards permeability, it appeared that, as in the case of the strength, there was a certain consistency for which the quantity of water passing through the mortar in a given time was less than for any other proportion. If the quantity of water used in mixing was progressively diminished, the permeability of the mortars produced increased very rapidly. In submitting, however, mortars mixed with different proportions of water to percolation, it was found that the very different initial permeabilities soon approached uniformity, owing to the gradual closing of the pores; so that the percolation of water caused the partial disappearance

of differences due to different proportions of water in mixing, as illustrated by the accompanying Table. In various experiments Mr. Feret.

TESTS OF MORTAR BRIQUETTES MIXED WITH DIFFERENT PROPORTIONS OF WATER. THE BREAKING STRAINS GIVEN ARE THE MEAN RESULTS OBTAINED WITH SIX BRIQUETTES OF 0·775 SQUARE INCH SECTION FOR TENSION, AND WITH TWO CUBES, HAVING SIDES OF 7·75 SQUARE INCHES, FOR COMPRESSION.

Composition of the Mortars by Weight.	Value of n in Relation to the Weights of the Dry Materials, Cement and Gravel.	Nature of Strain.	Briquettes kept in.	Interval which elapsed between Gauging and Testing.	Proportion of Water used in Mixing. Breaking Strain per Square Inch.					
					$0·7n$	$0·8n$	$0·9n$	n	$1·1n$	$1·2n$
	Per Cent.				Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1 Part of Cement to 2 Parts of Coarse Gravel.	11·9	Tension.	Sea-water.	12 Weeks.	231	222	241	246	213	168
			,,	1 Year.	260	271	247	253	254	224
			Air.	1 Year.	582	596	534	589	579	535
		Compression.	Sea-water.	12 Weeks.	1,633	1,704	2,031	1,747	1,491	1,392
			,,	1 Year.	1,960	2,386	2,414	2,599	1,917	2,031
			Air.	1 Year.	3,025	3,408	4,161	3,408	2,769	2,343
1 Part of Cement to 1 Part of Small Gravel.	19·7	Tension.	Sea-water.	12 Weeks.	267	239	291	256	253	247
			,,	1 Year.	359	359	395	373	359	349
			Air.	1 Year.	598	562	657	667	619	584
		Compression.	Sea-water.	12 Weeks.	1,818	1,917	2,130	1,818	1,491	1,349
			,,	1 Year.	2,031	2,244	2,173	1,988	1,960	1,534
			Air.	1 Year.	3,806	4,019	3,735	3,479	3,124	2,698
1 Part of Cement to 3 Parts of Small Gravel	17·0	Tension.	Sea-water.	12 Weeks.	214	190	165	159	136	141
			,,	1 Year.	274	261	264	261	234	236
			Air.	1 Year.	446	423	390	376	366	345
		Compression.	Sea-water.	12 Weeks.	852	866	766	568	582	497
			,,	1 Year.	1,065	1,093	1,008	824	781	753
			Air.	1 Year.	2,059	1,818	1,604	1,562	1,434	1,363

EXPERIMENTS ON PERCOLATION.

Composition of Mortar by Weight.	Proportions of Water for Mixing in Relation to the Weight of Dry Materials.	Average Efflux per Hour. During the two First Hours of Percolation.	Average Efflux per Hour. After one Day of Continuous Percolation.	Average Efflux per Hour. After four Days of Continuous Percolation.
	Per Cent.	Cubic Inches.	Cubic Inches.	Cubic Inches.
One part of cement to Five parts of fine sand	9	345	12	4
	12	25	8	4
	15	3	4	3
	18	9	4	3
	21	10	6	3
	24	10	5	3

Mr. Feret. on continuous percolation with sea-water, for determining the consistencies of mortar in which decomposition was most energetic, no definite law could be discovered. It appeared, therefore, that the amount of water in mixing exercised little influence on the decomposition of mortars, which was a natural consequence of the obliteration of the differences in the rate of percolation through similar mortars, mixed with different proportions of water, by the continual passage of the water. Nevertheless, a mortar mixed with too little water must be less compact and have more interstices than a very plastic mortar, and therefore must be more subject to the decomposing agencies of sea-water, as shown by Mr. Bamber's experiments, and also by some experiments made by Mr. Alexandre some years ago at Dieppe.[1] The foregoing remarks about mortars applied equally to concretes. Some experiments made at Boulogne [2] showed that concretes mixed dry might have greater strength than more plastic concretes, but that they were liable to have voids more or less large, which might become dangerous if these concretes had to be immersed in sea-water.

Mr. Kidd. Mr. W. KIDD observed that, in a recent Paper,[3] he had described a method of constructing the under-water portion of some exposed harbour works with slag cement concrete deposited *in sitû*. Having used slag cement extensively during the last four and a half years, in an exceptionally trying manner, with excellent results, and having carefully investigated its properties, he differed entirely from Mr. Bamber, that the "so-called iron slag cement" was "not a Portland cement," assuming the latter phrase to mean a hydraulic cement. The experience obtained in making and using slag cement might throw some light upon several obscure or uncertain matters. There were important differences between slag and Portland cements, more especially in regard to their chemical composition. The slag cement he had employed was made from Cleveland slag, the three principal constituents of which were lime, 30 to 33 per cent.; silica, 30 to 32 per cent.; and alumina and oxide of iron, 25 to 28 per cent. After the slag had been prepared, a proportion of finely powdered slaked lime was

[1] Annales des Ponts et Chaussées, 6th series, vol. xv. p. 375.

[2] Revue du Génie Militaire, July-August, 1891, p. 495. This article, and the Paper on the Boulogne experiments previously referred to, have been presented by Mr. Feret to the Institution library.

[3] Minutes of Proceedings Inst. C.E., vol. cv. p. 231.

ground up with it; and the finished cement, compared with an average Portland cement, was— Mr. Kidd.

Principal Constituents.	Slag Cement.	Portland Cement.
	Per Cent.	Per Cent.
Lime	45 to 47	59 to 61
Silica	24 to 26	21 to 23
Alumina and oxide of iron	20 to 22	7 to 11

Much uncertainty appeared to exist as to the proper proportions of the ingredients in Portland cement. While Mr. Bamber stated that "theory indicates that 50 per cent. of lime would be quite sufficient," Mr. Carey was of opinion that "the highest standard of quality is probably attained when 6 parts of lime, 2 parts of silica, and 1 part of alumina with iron, are present in combination." A cement, however, in which these proportions were 6, 2·5, and 1·8 (p. 42), affording a ratio of $\frac{\text{lime}}{\text{hydraulic factors}} = 1 \cdot 4$ in place of $2 \cdot 0$, gave results 40 per cent. stronger with neat cement, and 100 per cent. stronger with 3 to 1 mortar, than the other sample, whose ratio came nearer to Mr. Carey's standard. Slag cement contained only 45 per cent. of lime; and the proportion of the ingredients was $4\frac{1}{2}$ of lime to $2\frac{1}{2}$ of silica, and 2 of alumina; the ratio of $\frac{\text{lime}}{\text{hydraulic factors}}$ being only 1. This proved that a very good hydraulic cement could be made with proportions very different to those which usually obtained in Portland cement; and further, that even the 50 per cent. of lime, which, according to Mr. Bamber, "theory indicates as quite sufficient," was not absolutely necessary. The chief danger in Portland cement was the presence of free lime remaining after the concrete had set; this excess of lime, which had not combined with the silica, became dissolved by the action of sea-water, and caused a precipitation of the magnesium salts contained in the sea-water within the mass of the concrete, whence expansion followed, and failure was inevitable. Much appeared to depend upon the proportion of lime which became chemically combined with the silica; and he had nowhere seen it clearly stated what the relative proportions ought to be. In this connection, he should like to know what Mr. Carey meant by "sound cement" in his statement that "no conclusive evidence has been adduced to prove that the precipitates from sea-water induce disintegration, even of fissured or

Mr. Kidd. porous concrete, when sound cement is used." Did the analysis on page 63 represent a "sound cement" in Mr. Carey's opinion? Most Portland cements contained a proportion of lime perilously near the full amount which could be chemically combined with the silica; and there were many instances where there was an excess of free lime, whilst the high tensile strength now generally demanded increased this danger. At the Skinningrove works, they had proved that an extremely good hydraulic cement could be made, which contained 14 per cent. less lime, with 3 per cent. more silica, than Portland cement; this rendered it a much safer material for sea works, and it was remarkable that, with so low a proportion of lime, it was about twice as strong. With the sand test at twenty-eight days, the average of a large number of tests gave a breaking strain of 361 lbs. per square inch. Much uncertainty also existed as to the degree of chemical combination which took place between the various constituents in the process of setting. Both Mr. Carey and Mr. Smith characterized it as "feeble"; and both agreed that the degree of burning was the probable cause of this, the former remarking that "the degree of heat applied, and the time for which it is maintained, result in the production of comparatively rudimentary chemical compounds." He was of opinion that the much higher temperature of the blast-furnace, as compared with the cement kiln, was the true explanation of the difference in the composition of slag and Portland cements; and that, as a result of this, the chemical combinations were much more complete. Mr. Bamber's attempts to make Portland cement with 50 per cent. of lime corroborated this, as he had failed to clinker it by the ordinary method of burning, and found a higher temperature was required. He would suggest that a Portland cement containing a very low proportion of lime might be made by charging a small blast-furnace with chalk and clay in altered proportions, together with the necessary fuel; then using a temperature high enough to cause complete fusion, converting the raw materials into slag containing about 30 per cent. of lime; and lastly, granulating and grinding the slag, and adding the required proportion of slaked lime to be ground up very finely with it.

A new reason had been advanced by Mr. Bamber to account for "blowing," viz., the absorption of water by the coarse particles after the finer portion of the cement had set. It was stated by Mr. Carey, on the other hand, that Dr. Michaëlis had proved that these coarse particles were inert. It was true that the residual coarse particles, separated by a sieve, and gauged by themselves, had no cemen-

titious properties; but it did not follow that, when used along with the finer part, these particles were inert in the presence of water. "Blowing" had usually been attributed to the presence of caustic lime in the finished cement; and the usual remedy was to air-slake it thoroughly before use, an operation necessitating ten weeks' storage, in Mr. Carey's opinion; whereas Mr. Bamber considered that newly-ground cement, if properly mixed, was perfectly safe and reliable. Very few engineers would accept the risk of using newly-ground cement; but in practice, the time required to complete the usual tensile tests rendered it unnecessary to do so. In using slag cement, he found it had no tendency to "blow" or expand, even when freshly ground, the free lime having been all thoroughly slaked before being added to the slag preventing this. There was, however, a tendency to contraction when used in air; and a length of new work would sometimes separate from the old work by a fine hair crack, owing to its highly aluminous character. From the same cause, it did not retain such a hard skin in air as Portland cement; but below tide-level both of these objectionable features disappeared. In grinding slag cement, a machine was used in which the cement was pounded rather than ground. In practice it was ground very fine, the residue being only 15 per cent. on a sieve of 32,000 meshes per square inch. He would go further than Mr. Carey's specification in this respect, and grind Portland cement equally fine. This would result not only in greater strength, but, what was more important, he believed that the chemical combination would be much more complete. Fine cement was objected to on the score of expense only; but it should be remembered that an extra cost of say 3*s.* per ton of cement for grinding, only added about 8*d.* to the price of a cubic yard of 5 to 1 concrete, even when the same quantity of cement was used. As, however, the 3 to 1 mortar test showed an increase of strength of about 50 per cent., a smaller quantity might be used. As 8*d.* worth of cement would be about half a cubic foot, or only 10 per cent. of the quantity, this reduction could be made and still leave a net gain of strength in the concrete. In sea work, however, apart from the question of fineness, the full quantity of cement required for making the mixture impermeable must be used, independently of the question of strength; and a fine cement would possess the additional advantage of making a more impermeable concrete than an equal quantity coarsely ground. Mr. Kidd.

Very great diversity prevailed in the proportions used in making concrete. In concrete exposed to sea-water, the pro-

Mr. Kidd. portion of cement to sand should be as high as possible. However suitable concrete of 10 or 12 to 1 might be for various other classes of work, it should not be exposed to the action of sea-water, as the porous character of such concrete greatly facilitated the injurious chemical action to which it would be subject. Using broken stone of various sizes, he had made concrete of 5 to 1, having a proportion of cement to sand as high as 1 to 1, large stones being added. A matrix of 1 cement to 2 sand, would unite 6 parts of broken stone, forming good concrete of 8 to 1, impermeable in a high degree, and affording very little opportunity for the action of sea-water; and he was of opinion that to put concrete weaker than 8 to 1 into any exposed sea structure was a mistake, in the light of recent experience. These latter were the proportions he would advocate for making blocks which were allowed to harden before being put into the sea. For "mass" work deposited *in sitû*, he had used 5 of stones, $1\frac{1}{2}$ of sand, and 1 of cement, making a concrete of $6\frac{1}{2}$ to 1, when deposited between high- and low-water levels. Such a concrete made with a good Portland cement, low in lime, well burnt, and very finely ground, and composed of clean materials, thoroughly well mixed and properly deposited in place, was capable of resisting the chemical action of sea-water. His experience in Portland cement concrete in sea structures at the harbours of Blyth[1] and Eyemouth, both below and above water, had resulted in producing work which was quite sound, showing no signs of deterioration, except in some places where it had been deposited below low-water, where subsequent examination in a diving-dress showed that layers or pockets of soft cement or "laitance" had accumulated, which rapidly dissolved, leaving holes, but in no case of much importance. In depositing concrete by tipping from barrows and wagons, or down shoots, the materials invariably became separated, thus causing porosity, including the "accidental voids between stones and mortar" to which Mr. Smith had alluded. He had adopted the practice of depositing all concrete by means of iron boxes, with opening bottoms, lowered into position by cranes; this made very good work, it was economical, and had other advantages in sea works.

Mr. Colson. Mr. C. Colson had alluded on former occasions[2] to the fallacy of taking the weight of cement as a test of quality, and thought that a specific gravity test should be substituted, as giving

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 302.

[2] *Ibid.*, vol. xli. p. 125; vol. liv. p. 264; and vol. lxii. p. 213.

Mr. Colson.

positive evidence of hard burning. He attached great importance to thoroughly cooling the cement before use, chiefly to reduce the caustic lime, and also to get rid of the heat imparted by grinding. Cement had frequently been delivered on his works, after a voyage of some 2,000 miles, too hot from grinding to be used until cooled. The tensile strength required at seven days was, in his opinion, being carried beyond the limits of prudence. A sound, well-burnt cement, bearing a strain of 300 lbs. to 350 lbs. per square inch at seven days, or 550 lbs. at twenty-eight days, was strong enough for all practical purposes, and could be used with confidence.

In advocating some supervision of the manufacture of Portland cement, he presumed that Mr. Carey did not intend the user to take any active part in the details of manufacture. While the right of inspection at all times should be secured, any clause giving the inspector control over the manufacture would be very unwise, and might lead to complications. The chief duty of the inspector should be to determine the quality of the finished cement by chemical and mechanical examination, and to see that the cement, after being tested and passed, was not tampered with, leaving the whole responsibility of its preparation on the manufacturer. He had before referred to the valueless character of the residue after screening,[1] and longer experience had confirmed his views. Hitherto expense had been pleaded as a bar to greater fineness, but with improved appliances and longer experience this should no longer be the case. In referring to the sieves for testing the fineness of cement, no allusion had been made to the gauge of wire to be used, a matter of great importance, inasmuch as, if the number of meshes per square inch were specified only, wire of an undue fineness might be used, with a corresponding increase in the size of the holes. For a 625-mesh sieve, a wire of 34 B. W. G., and for a 2,500-mesh sieve, a wire of 37 B. W. G. was adopted in some specifications, with a residue of 10 per cent. on the latter sieve; but a 5,000-mesh sieve, with the same gauge of wire, might be used with not more than 10 per cent. residue, and still better with no residue.

The threefold tensile test at three, seven, and twenty-eight days, proposed by Mr. Carey, required further explanation. For instance, if a sample of cement complied with the three and seven days' test, but failed at the twenty-eight days' test, it would, in the terms of the specification, be condemned; but if it complied with the third test, and failed in the first and second, or if it complied

[1] Minutes of Proceedings Inst. C.E., vol. lxi. p. 127; and vol. liv. p. 265.

Mr. Colson. with the first and third, and failed at the second, would the cement be rejected, as in accordance with the strict reading of the clause, it should be? With such a threefold condition, however, complications might arise from inexpert testing; and therefore it might be better to adhere to the twenty-eight days as the crucial test for tensile strength. It was not at all unlikely that, in the near future, the method of hot tests might be substituted for the present method. In positions where a face of superior quality was necessary, such as in culverts, or other parts subject to a strong rush of water, instead of using a thin facing of better concrete, or rendering with neat cement, neither of which he had found altogether satisfactory, he had applied a rendering of neat cement, from 1 to $1\frac{1}{2}$ inch thick, to the casing just before the concrete was deposited. The mass being then well rammed, the neat cement rendering became incorporated with the concrete next the casing, forming a skin without any joint between it and the general mass. He fully approved of tests being made with sand in preference to testing the neat cement, provided the sand was of an absolute standard quality, both as regards size and composition, otherwise the results would be fallacious. The tests also should be made by experts, and under conditions obviating any chance of contamination of the sand. In numerous experiments made with sand, supposed to be purely silicious, he had never found any sample absolutely free from calcareous particles, the presence of which in a varying degree affected the results of tests. To obtain a material for experimental purposes as free as possible from all such calcareous matter, the best silicious sand procurable was reduced to a uniform size by screening, and was afterwards washed in an acid bath for some days, to remove all calcareous matter; and calcareous sand prepared from limestone, and brought to the same size of grains, was then added in small but increasing percentages. Tests blocks made with sand to which calcareous matter had been added, were superior in tensile strength to those made with the pure silicious sand. The possibility of calcareous or other absorbent material being added to the silicious sand was a weak point in sand tests, on which grave issues might arise.

The more thoroughly concrete was rammed, the more sound and impervious the mass would be, and consequently the less liable to injury from the action of water. He did not think it had been conclusively proved that the action of the magnesia in the sea-water was the primary cause of the very serious defects observed at Aberdeen. Doubtless it found out the weak places, and augmented the evil; but the first cause might be

found in the composition of the concrete. The proportion of sand was nearly double that required to fill the interstices of the stone, while the proportion of cement was very much less than sufficient to fill the interstices of the sand. The bulk of the mass must therefore have been composed of mortar of a weak, porous quality, through which the water would very readily find its way. He would hesitate to pass concrete of such proportions through water. If sound, cool cement was used in a proportion thoroughly filling the interstices of the sand, and the resulting mortar was just sufficient to fill the interstices of the stone, after allowing for a little waste in manipulation, and the whole was carefully trimmed into place and well rammed, so as to produce an impervious mass, and if, where the concrete had to be passed through water, it was mixed with an extra quantity of cement, and deposited with every precaution against wash, in as large quantities as possible, he did not think much would be heard of concrete failures on a large scale, or of Portland cement being unsuitable for use in sea-water. Mr. Colson.

Mr. W. Redfern Kelly remarked that failures of sea works such as those at Aberdeen and in other similar structures made of Portland cement concrete, especially commended themselves to the attention of the harbour engineer. Undoubtedly as little magnesia as practicable should be allowed in the Portland cement used in sea works. Owing to the high tensile tests so often required, the production of over-limed cements had unfortunately become a necessity with the manufacturer. If more attention was paid to the sieve and specific gravity tests, and less to abnormally high tensile tests, and if proper attention were also paid to the aeration of the cement and to its subsequent treatment in making concrete, less blowing would result, which so often led to disruption, in the development of which magnesia played so prominent a part. He agreed with Mr. Carey as to the uncertainty of the test by weight of Portland cement; and very fine grinding was most important, for though involving a higher price for the cement, it was ultimately economical. Notwithstanding Mr. Carey's objections to standard regulations for testing Portland cement, he was of opinion that, owing to the proficiency attained in the manufacture, the present would be a most opportune time for their initiation. With standard regulations, manufacturers would be competing on equal terms, and the user would be benefited. The seven days' test was much too short, and a twenty-eight days' test should be insisted upon before accepting the cement; and, the seven days should include, not Mr. Kelly.

Mr. Kelly. only the immersion period, but the time occupied by the gauging and setting of the briquettes, before placing them in the water; and, further, the mortar test, with 1 of cement and 3 of sand, should invariably be adopted. Whilst considering Mr. Carey's standard specification fair and workable, he would prefer a lower tensile test. Failures in concrete works were not always due to the use of inferior Portland cement, but might often be ascribable to the incorrect proportioning of the ingredients and the improper manufacture of the concrete. Even with the use of superior mechanical concrete mixers, which ensured the thorough incorporation of the various ingredients, errors invariably occurred in the application of water. In some cases the concrete was absolutely drowned, whilst in others it was much too dry; and many failures of concrete works might be traced to inexperience or inattention in the latter respect. The stability or durability of structures in the sea depended greatly upon correct proportions of the materials for the concrete, especially where the unbalanced pressure of tidal water had to be dealt with, as in graving docks, entrance locks, &c. Too liberal a proportion of sand was often introduced, which deprived the other ingredients of their proper share of cement; and very often sufficient attention was not paid to the granular texture of the sand. A rather coarse, sharp, or angular sand formed a much better concrete than a fine, though sharp sand; and pit sand free from clayey or earthy matter, or river sand free from peat, vegetable fibre, or other impurities, would prove much better than the sea sand often adopted for convenience and economy. But, notwithstanding its fulfilment of the conditions of coarseness, angularity, and freedom from impurities, if sand was used in too great quantity, porosity or permeability of the mass would result.

Mr. Cay. Mr. W. Dyce Cay had observed that when the failure of the Aberdeen graving dock was on the *tapis*, the damages sustained by the South Breakwater there were brought well to the front. Mr. Cay had already described the South Breakwater,[1] and also the cause of a breach [2] made in the sea face, near the rocks, in 1883. Mr. Smith had given a description of this breach and other damages to the work,[3] and of the repairs executed by him; and judging from the expenses of maintenance given, Mr. Cay thought it probable that the cost of repairs of damages due to wave action,

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[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 126.
[2] *Ibid.*, vol. lxxxvii. p. 201.
[3] *Ibid.*, vol. lxxxvii. p. 217.

Mr. Cay.

as distinguished from those due to chemical action, and wear and tear, amounted to about £7,500. This seemed a large sum, as the volume of the holes was only about 1,100 cubic yards, besides what was required to form an apron 100 feet in length. He also thought that the progress of the injury might have been stayed in the winter and spring of 1882–3, by bundles and tangles of old chains, a plan he had previously adopted in winter time in stopping damage at the old north pier-head; whereas nothing appeared to have been done till the middle of May. The expense of the repairs was much increased by the new work and temporary framings being swept away by the sea on several occasions; but no doubt it was a very difficult site for the execution of such work, as the sea was concentrated upon it by the outer part of the breakwater. If, however, £7,500 was the cost of repairing the damage caused by the wave action, deducting that from the £11,000 given in Mr. Smith's Paper, only £3,500 remained as the cost of repairs to the South Breakwater in the eighteen years since its completion, including wear and tear and chemical action of the salt-water, a very trifling amount comparatively speaking, and an encouragement to engineers that, with reasonable precautions, such works could be constructed with Portland cement concrete so as to be both durable and economical. With regard to the graving dock, it had been so fully reported on that little remained to be said. The specification of the cement, however, was not such as he would approve of, viz., 5 per cent. residue on a gauze sieve having a thousand holes per square inch; weight 115 to 124 lbs. per bushel; and neat cement tests, twelve hours in air and seven days in water, to stand an average tensile strain of 1000 lbs. on a section of $1\frac{1}{2}$ inch $\times$ $1\frac{1}{2}$ inch, and no mortar tests. There was thus no security as to the fineness of the cement, as a coarse cement might pass these tests as well or better than a fine one. Accordingly, owing to the proportion of coarse inert grains in the cement, the concrete might be much weaker than the proportions specified would at first sight indicate. He had given his views on the action of sea-water on Portland cement in a previous discussion,[1] and had shown that the conclusions of the chemists and engineers on the Aberdeen graving dock had been anticipated many years before by Vicat and others. The most remarkable writings on the subject he had since seen were those of Mr. M. H. Le Chatelier;[2] but neither of these eminent chemists

[1] Minutes of Proceedings Inst. C.E., vol. c. p. 86.

[2] Annales des Mines, 8th Series, vol. xi.

Mr. Cay. gave any hope or practical means of overcoming the destructive action of sea-water on cement concrete, and they must still rely upon what Vicat called the cohesion resulting from the solid structure of these compounds to attenuate or paralyze the action of the magnesian salts. Every practical means should therefore be adopted to render the concrete impermeable, so as to confine the attack to the surface, such as great fineness of the cement, mixing the concrete thoroughly by steam power, proper proportion of water of mixture,[1] relative sizing of the aggregates, and placing the concrete *in sitû* as soon as possible after mixing without disturbance of its proportions.[2] In reference to "plastic" concrete, experiments by Mr. E. Candlot[3] showed that mortars regauged or worked up again were more rapidly decomposed by sea-water than mortars gauged normally.

With regard to testing, he thought the use of heat to quicken the chemical action in the test briquettes, and to put in relief the causes of destruction, as advocated by Mr. Le Chatelier, was a valuable suggestion, as it would shorten the time required for the test. He proposed to let the briquette set during twenty-four hours at the ordinary temperature, then to keep it forty-eight hours in hot water near the boiling point, but not in ebullition, which would bring out the greater part of the effects of swelling and internal disaggregation, due to excess of carbonate of lime in the kiln or insufficient burning. At the end of seven days, the maximum tensile strength would be obtained. Then the tests would be completed by desiccation of a briquette in dry air at 212°, causing the destruction of hydrates of small stability, and thus relegating quick-setting cements to their proper place, which cold tests at short periods might have enhanced. The specific gravity test had the objection that, besides the true cement clinker, all the other products of the kiln, except the yellow insufficiently-burnt lumps, had about the same specific gravity. The best security was inspection at the manufactory, as advocated by Mr. Carey, and carried out by the French Public Works department, though the other tests could not be neglected.

Mr. Colson. Mr. C. H. Colson had lately made a series of experiments to test the watertightness of concrete, subject to a constant head of about 46 feet, and in a position where this quality was of the utmost importance. The blocks tested were 2 feet × 2 feet × $1\frac{1}{2}$ foot, some

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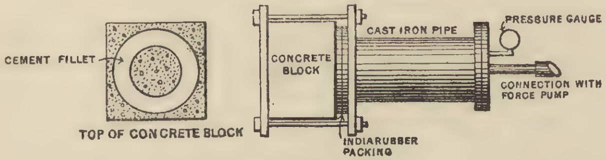
[1] Annales des Ponts et Chaussées, 6th Series, vol. xv. p. 816.
[2] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 198.
[3] Commission des Chaux, Ciments et Mortiers, July, 1890.

made from hand-picked stone, and some from stone as used in the works; and some were cut out of the work in progress. All the concrete had been thoroughly mixed by hand, deposited in 9-inch layers, and carefully rammed to consolidate it. The improvised testing apparatus (Fig. 3) consisted of a cast-iron cylinder, 12 inches in diameter, with a hydraulic pressure-gauge attached reading to the square inch, connected at one end to the block to be tested, and at the other to a pressure pump. The blocks were prepared for testing by removing the top skin and putting on a cement ring of the size of the flanges of the cylinder, the space inside the ring being kept quite clean. At 20 lbs. pressure per square inch there was a slight appearance of dampness in some of Mr. Colson.

Fig. 3.



Scale 4 feet = 1 inch.

the blocks, but in no case, even with the highest pressure, was there much percolation.

RESULT OF EXPERIMENTS.

Proportions of Concrete.			Age of Block when Tested.	Number of Hours during which Extreme Pressure was kept up.	Pressure applied in lbs. per Square Inch.	Depth to which Percolation extended from Side to which Pressure was applied, at end of Test.
Stone.	Sand.	Cement.				
Parts.	Parts.	Parts.	Days.	Hours.	Lbs.	Feet. Inches.
7	3	2	47	2	30	..
7	3	2	58	2	30	..
7	3	1½	44	1½	30	6
7	3	1½	48	2	30	7
7	3	1½	50	2	30	8
7	3	1½	52	2	30	..
7	3	1	33	2	30	10
7	3	1	53	2	30	10
7	2	1½	19	2	30	4
7	2	1½	21	2	30	..
6	3	1½	51	2	30	6
6	3	1½	57	2	30	..
6	3	1	48	2	30	1 6
6	3	1	42	2	30	1 6
6	3	1	50	2	30	1 0
8	4	2	50	2	30	10
8	4	2	56	2	30	1 0
8	3½	2	29	2	30	10

Mr. Dyckerhoff. Mr. R. DYCKERHOFF stated that, from experiments with various fluids which acted injuriously upon cement, such as mineral waters, sea-water, various kinds of oil, &c., he had found that these fluids only damaged Portland cement, mortar, and concrete, when they could penetrate the mass. For example, porous mortar (1 of cement to 3 of sand) might be completely destroyed by fatty oil, while dense mortar (1 of cement to 1 of sand) was not attacked by it; and the progress of hardening of experimental masses (1 of cement to 1 of sand), laid in oil, was not delayed. It was similar with sea-water, as Mr. Messent's trials showed. Therefore, in cement structures which had to withstand the destroying influence of certain fluids, the mortar must be impenetrable; and he agreed with Mr. Smith, that only impermeable mortars should be used for structures in the sea. In his opinion, it was not necessary that the entire mass of a pier or breakwater should be built up with the strongest Portland cement mortar (1 to 1 or $1\frac{1}{2}$), but only the outer layers, which had to withstand the mechanical action of the waves. The principal mass in the interior could be put together with a weaker mortar, rendered impermeable by adding lime. Thus, he had ascertained by experiments that a mortar of 1 of Portland cement to 3 of sand, with the addition of slaked lime in the proportion of $\frac{1}{2}$ by volume or $\frac{1}{4}$ by weight, would become stronger during the hardening in sea-water than the same mortar without the addition of lime. For mortar in the interior of a pier, which in ordinary cases had only to withstand the chemical action of sea-water, a mixture of 1 measure of Portland cement to 1 of slaked lime, and 3 to 4 of sand, with an adequate addition of gravel in the case of concrete, seemed entirely satisfactory. As structures in the sea had, in addition to the chemical action of the sea-water, to resist the force of the waves, only the densest, hardest, and most resisting material should be used, and there was none more suitable than Portland cement. Regarding the injurious action of magnesia as a constituent of cement, he would refer to his own Papers,[1] and to the Proceedings on this subject in the Reports of the Society of German Cement Manufacturers.

Mr. Eliot. Mr. WHATELY ELIOT believed that the failure of Portland cement concrete was more often caused by defective manipulation of the ingredients than by inferior cement. In his experience, there was no difficulty in obtaining in this country cement which, if properly

[1] "Protokoll des Vereins deutscher Cement-Fabrikanten," 1889, p. 24, 1890, p. 36.

used, should ensure success. The other ingredients should also be selected with equal care, and used in proper proportions of the various sizes, and all should be thoroughly mixed together. Frequently too much sand was used, and sometimes an undue proportion of rough stones, either of which would be detrimental to the concrete. To prevent blowing, and consequent injury to the concrete, the cement should be thoroughly air-slaked before use. He had largely used Portland cement in sea works, but had never experienced any deterioration due to the chemical action of sea-water, although the concrete had in some instances been covered by the tide soon after being mixed. Concrete for sea works should be made as compact as possible, and with a smooth face, otherwise holes would be left which could not be efficiently stopped by patching afterwards, and were liable to be enlarged by heavy seas. He could bear witness to the destructive effect of compressed air, as noticed by Mr. Smith in cavities of the south breakwater at Aberdeen, having had a similar experience in a sea-wall at Peterhead, where stones were forced out from the face of the wall by the compression of air in the joints round them, due to the blows of waves. Mr. Eliot.

Mr. M. FITZMAURICE remarked that the effect of frost on cement mortar and concrete was of vital importance in cold countries. On the Chignecto Ship Railway, in Nova Scotia, it was necessary to continue building operations rather late in the season. Night frosts commenced there about the end of October, and, though fairly warm during the day-time in the early part of November, the frost was very severe at nights, the thermometer often going down to zero. As building was continued until the middle of December 1890, there were very good opportunities of observing the effects of frost on large masses of concrete and masonry, and also of making some experiments with cement briquettes. In the first series of experiments, ten briquettes were made of neat cement; of these, four were kept in the house, four were exposed to frost for four days and then brought into the house, and two were exposed to frost for twenty-eight days; and they were all broken after twenty-eight days. Those not exposed to frost broke at an average strain of 495 lbs. per square inch; those exposed to frost for four days broke at 421 lbs., showing a loss of strength of 15 per cent.; and those exposed to frost for twenty-eight days broke at 320 lbs., showing a loss of 35 per cent. In the second series, ten briquettes were made of 3 of sand to 1 of cement, and were treated similarly to those in the first series. Those not exposed to frost broke at 240 lbs.; those exposed for four days broke at 155 lbs., Mr. Fitzmaurice.

Mr. Fitzmaurice. showing a loss of 35 per cent.; and those exposed for twenty-eight days broke at 104 lbs., showing a loss of 56 per cent. In the third series, four briquettes were made of 3 of sand to 1 of cement; two were kept in the house, and two were exposed to frost for four days and then brought in; and they were all broken after fifty-six days. Those not exposed to frost broke at 270 lbs.; and those exposed for four days broke at 194 lbs., showing a loss of 28 per cent. During the time the briquettes were exposed to frost, the temperature varied from 32° to −10° Fahrenheit. Evidently, even in long time experiments, frost had a very marked influence on the strength of briquettes. The much smaller percentage of loss with the neat cement briquettes than with the 3 to 1 briquettes was natural, as the loss of strength depended very much on the extent to which setting had taken place before being exposed to frost. The briquettes exposed for twenty-eight days might reasonably have given worse results, owing to having had so little chance of setting. A block of concrete, 3 feet long by 1 foot by 1 foot, of 1 of cement to 6½ of gravel, was made in a box, on December 16th, when the temperature was below freezing, and it went down to −2° that night. The box was left in the open until April 15th, there having been no frost for some time before that date. On examination, no sign of setting was apparent; and the whole block could be picked out with a stick. From careful examination of large masses of masonry and concrete, it did not appear that, when proper care was taken, the effects of frost were so bad as indicated by the above experiments, if the concrete or mortar was not laid when actually frozen. During December, masonry and concrete were laid for some hours during the middle of the day, if the temperature got up to about 26°. Before laying any masonry or concrete, all ice was carefully picked out, a steam hose played over all the places where any masonry or concrete was to be deposited for fifteen or twenty minutes, and each stone was well steamed. The temperature at nights often went down to −10° Fahrenheit at this time. In the spring, the work which had been done in this way was examined, and some of it picked out; and it was found perfectly sound, except the top 2 inches of concrete. No salt was used in the water on these works. It therefore appeared that concrete and masonry work could be carried on safely in comparatively cold weather if the concrete was mixed under cover, and if, by use of steam or other means, care was taken not to deposit it actually frozen, or on material already frozen; in fact, on large works the difficulties of working cranes, engines, and boilers in extreme cold

would probably stop the work before the masonry or concrete would suffer to an appreciable extent. Mr. Fitz-maurice.

Mr. J. P. Griffith remarked that Portland cement had been used in the Port of Dublin for more than a quarter of a century; and the earliest works in which it was adopted remained as monuments of its usefulness and reliability. For many years he had advocated conferences between cement manufacturers and engineers as to the adoption of standard tests in this country. A study of the effects of such tests in Germany had satisfied him that none of the drawbacks which Mr. Carey anticipated had arisen from the united action of manufacturers and engineers. So far from retarding the improvement of the manufacture, the progress made in Germany had been greater than in England during the last few years. In fact, the tendency to seek for a high seven days' tensile stress in English specifications had led to the manufacture of dangerous cement. The German standard rules of 1887 did not refer to any chemical analysis, or to the specific gravity of the cement; and possibly Mr. Bamber could say whether later rules had been issued incorporating either of these tests. If not, it would appear that the German engineers and manufacturers had not agreed as to the need for them. He should like Mr. Bamber to give his opinion on the conditions which influenced the time of setting of cement, and whether he thought it desirable to introduce a limit for the time. He also wished that Mr. Bamber would express his views as to the desirability of insisting on a twenty-eight days' test, in addition to the seven days' tests, and whether an increase of strength, say of 20 per cent., over the results obtained at seven days, might not reasonably be expected. Mr. Bamber's opinion as to the need of continuing the German sand test would be of interest, for this was a debatable point even in Germany. It proved the value of fine grinding; but now that fineness was admitted to be a necessity, and could be determined by sieves, might not a test which was dependent on the character of the sand, as well as on the quality of the cement, be omitted, and the strength of the neat cement, together with the test of fineness, be sufficient? Tests, to be of real use, should be as simple as possible; but some of the proposals could only be carried out on large works, with inspectors to visit the cement works, and chemists to analyse the cement, which failed to meet the urgent daily needs of most engineers. Few engineers using Portland cement required cargoes of it, but all required reliable cement; and, therefore, he strongly advocated an agreement between the Institution and manufacturers, believing that this must result in Mr. Griffith.

Mr. Griffith. better cement being manufactured at a cheaper cost. The failures at Aberdeen should be thoroughly investigated, and it would materially assist in doing so, if Mr. Smith would give the results of the tests of the cement before it was used in the work. Mr. Messent's report gave the specification of the cement to be used in the Aberdeen graving dock; but Mr. Smith had not stated that the cement used complied with this specification. The cement must have been very coarse in order to comply with the weight tests, and the sieve mentioned was not fine. A high seven days' tensile test was also required. The requirements might have been fulfilled by dangerous cement, and disintegration might have resulted by the expansion due to the gradual absorption of water by the coarse particles of the cement. He had only once met with a cargo of such cement; it passed the seven days' tests satisfactorily, but showed signs of disintegration within a month after gauging; and this disintegration continued for years, until the briquettes became a granular mass. Such a disintegration might have gone on at Aberdeen, rendering the concrete porous, and allowing the passage of the sea-water. As soon as this percolation was established, the removal of lime, and the deposition of magnesia followed naturally.

Mr. Mann. Mr. I. J. MANN considered that the tests generally applied to Portland cement required revision in the direction of fineness of grinding, specific gravity, and chemical analysis. All failures that had come under his observation had occurred between high and low water; and although, in some instances, the failure was attributable to bad workmanship, and insufficiency of water in mixing the concrete, some failures could only be explained by inferiority of cement, which was disintegrated by alternate exposure to air and sea-water, and the joint chemical and mechanical action of the latter.

Mr. Mansergh. Mr. MANSERGH said that in his work concrete had usually to be made watertight, and for many years he had insisted upon much more water being used in the mixing than was sometimes approved of, as it was otherwise hopeless to make concrete like a close compact impervious conglomerate, as obtained with 5 of clean, hard grit stone and sand to 1 of cement. More first-class material was made into bad concrete for want of water than of cement; and the soundness of weak concrete, when properly put together, was remarkable. Ample water was also needed to form the materials into a stiff slurry-like mass, from which the larger stones were not easily separated. A cylindrical chamber, about 30 feet in diameter, of 10 to 1 of concrete, and 2½ feet thick,

Mr. Mansergh.

intended ultimately to be rendered and lined with brickwork, proved watertight with 10 feet of water in it. As a contrast, he had a few years ago examined the concrete tongue of a storage reservoir, gauged 5 to 1, but put together much too dry, through which water, poured on a horizontal surface, passed freely through 5 feet in less than two minutes. In a second reservoir failure, the contractors brought him a lump of concrete cut out of their work to show how good it was; but he found that, although sound in itself, there was a fine skin of dried silt between the joint surfaces. Pumping being stopped at night, dirty water had risen over the work, and the deposit from it not being washed off before more concrete was added, formed horizontal joints, through which water under pressure had squirted in sheets as if from a hose spreader. He saw an exactly similar failure in a sea wall at a sea-coast watering-place some time ago, which, in falling forward, had broken into blocks at the dirty partings.

Mr. Messent.

Mr. P. J. Messent observed that, referring to the concrete disaster at Aberdeen, Mr. Carey had given (p. 30) an incorrect summary of his (Mr. Messent's) report, instead of quoting the summary in the report itself, which was given in Mr. Smith's Paper (p. 49). Mr. Carey next (pp. 30 and 31) described some experiments with briquettes immersed in the sea at Newhaven. They were weighed before and after the bath, and gave a result from which Mr. Carey seemed to believe that he had proved that good cement could not be injured by the deposit of magnesia from sea-water. The arrangement of these experiments showed a disregard of many of the important portions of the Aberdeen report. If Mr. Carey had wished to ensure that the briquettes should be secured from any deterioration by magnesia, he could hardly have devised a means by which his object would be more effectually attained. The report stated (p. 18):—

"I would again call attention to the quantity of magnesia contained in sea-water, viz., one-five-hundredth of its weight. It therefore requires five distinct changes of sea-water, in contact with the same weight of cement, to deposit in the cement one per cent. of its weight of magnesia (supposing it to deposit all that it contains); and as the mortar portion of concrete, say when the cement and sand are as one to three (the cement forming one-fourth of the whole), absorbs about one-eleventh of its weight of water, it would require fourteen complete changes of water to form a deposit of 1 per cent. of magnesia in the cement, or fifty-six complete changes, or its equivalent, in order to produce the injurious quantity of 4 per cent. of magnesia. As above stated, on account of the capillary attraction, or retentive power of mortar, such changes are not readily made, unless there is pressure and forced percolation, or evaporation. Where the concrete structure is in the sea, and the tide rises nearly simultaneously on both

Mr. Messent. sides, or around it, there is no tendency, under ordinary circumstances, to produce forced percolation; whilst the only portions subject to evaporation, would be those portions left dry for several tides during neap-tides."

In the report it was shown (pp. 13 and 14), that after immersion in sea-water, "a mixed one to three briquette absorbed in two hours (after which it absorbed no more) about 9 per cent. of the weight of the briquette," and no perceptible exudation of water took place for more than six hours after the briquette had been taken out of the water and left to dry; and "after ninety-six hours, in an average temperature of 45° Fahrenheit, it had only lost 53 per cent. of the total water absorbed." From the above quotations, it would be seen that it was contended that, in the absence of forced percolation, in order to introduce 4 per cent. of magnesia into the cement mortar (1 cement to 3 sand) there must be fifty-six complete changes of the sea-water that it was capable of absorbing, supposing the whole of the magnesia to be deposited. It was also shown that a briquette did not begin to exude the water that it absorbed for six hours after leaving the water; whilst in ninety-six hours it lost little more than one-half. Now, as Mr. Carey placed his briquettes at the level of low-water spring-tides, where they would only be out of the water for about an hour each tide during the spring-tide week, and would be constantly immersed during the neap-tide week, the briquettes would have no opportunity of exuding the water absorbed on their first immersion, which would prevent the ingress of more water, or the deposit of any magnesia beyond what was contained in the first quantity absorbed. Had the experiment been continued for as many years as months, the result would have been the same. A trustworthy result might have been obtained (in the absence of conveniences for producing forced percolation) by immersing the briquettes for three to six hours every fourth day, keeping them in a dry place in the intervals for them to exude as much as possible of the water absorbed at each immersion. If the briquettes were separated into groups according to their respective compositions, by weighing them before and after each immersion, the total quantity of sea-water absorbed in each group might have been ascertained. Another plan, corresponding with one of the positions indicated in his report (p. 19), would have been to place the briquettes above the level of high-water neaps, but below high-water springs, when they could have exuded during neaps the sea-water absorbed during springs. Mr. Pattinson, who made the analyses for his report, had written to him on this subject as follows:—

Mr. Messent.

"The futility of the experiments made by Mr. Carey on the disintegrating action of the sea-water on cement ought to be pointed out. According to the description of the experiments given on page 30, the briquettes were simply immersed in sea-water; and no means were taken to make the sea-water filter through the briquettes in the manner in which the sea-water had been forced through the concrete which gave way in the Aberdeen dock. In Mr. Carey's experiment, the briquettes would simply become saturated with sea-water, and the same water which entered at first would be almost the only water which would penetrate the briquettes. In the Aberdeen case, large quantities of sea-water would be forced through the concrete by pressure; and not only would much of the lime be decomposed and washed away, but probably much of the precipitated hydrated magnesia would also be washed away by the current, and only a small part of the precipitated magnesia left in the concrete would be found in the portions of partially disintegrated concrete examined."

He failed to see the object of the experiments on using sea-water in gauging cement so far as the magnesia question was concerned, for the magnesia could have no perceptible deteriorating effect, forming only $\frac{1}{500}$ of the 20 per cent. of water used, or $\frac{1}{2,500}$ of the briquette: or, even if increased to $\frac{1}{1,250}$ by the evaporation of half of the water, it would still be a harmless dose. Before commencing his investigation at Aberdeen, his bias was rather against than in favour of the failure being due to chemical injury from sea-water. He found the work at Aberdeen very much as that described by Mr. Hayter at Maryport, the concrete portion of the walls, especially near the entrance, being bulged and disintegrated, whilst water was leaking freely through pores and fissures in the concrete, the deterioration being below high-water spring-tide level. The analysis of the deteriorated, and of the apparently undeteriorated concrete, taken from solid portions of the walls, showed that all the deteriorated concrete contained from 4·29 to nearly 40 per cent. of magnesia in proportion to the cement; whilst the undeteriorated specimens, although composed of similar materials (cement, sand, and broken stones), mixed by the same workmen at no great interval of time between the respective mixings, contained no more magnesia than the original cement and sand, namely, between 1 and 2 per cent. It was therefore impossible to come to any other conclusion than that the large quantity of magnesia in the disintegrated concrete was the cause of its deterioration. Other portions of the concrete constructed of the same materials, but not containing an excessive quantity of magnesia, remained intact. The next question was, how the injurious quantity of magnesia got into the deteriorated concrete. All the deteriorated specimens were wet with sea-water which had contained about 0·002 per cent. of magnesia, a quantity apparently insignificant and harmless, unless the contact of the sea-water was often repeated. Percolation under pressure seemed

Mr. Messent. the most likely means of extracting magnesia from the sea-water; and this was facilitated by the holes in the comparatively watertight outside plaster, with the extremely permeable concrete behind. Whilst the mortar of all the deteriorated specimens was composed of 1 of cement to 3 and 4 of sand, the plaster and mortar composed of 1 cement to 2 and $1\frac{1}{2}$ of sand, and stronger, were undeteriorated, although made of the same cement and sand, and exposed to similar sea-water contact and pressure. Subsequent experiments showed that sea-water, passing under pressure through a 1 to 3 briquette, $1\frac{1}{2}$ inch thick, deposited in about ninety hours nearly half of the magnesia that it contained, equal to an increase of 4 per cent. on the cement of the briquette, and that 1 to 3 cement mortar would allow nearly ten times as much water to pass through under pressure in a short time as would pass through 1 to $1\frac{1}{2}$ cement mortar in the same period. Later experiments showed that strong cement mortar, even exposed to forced percolation, became comparatively impermeable after a short time. From these facts, he had no hesitation in arriving at the conclusion that the deterioration of the concrete at Aberdeen was caused by the abstraction of lime and deposit of magnesia by the sea-water which percolated through the concrete under pressure, and that the inappropriate composition of the mortar of the concrete facilitated the percolation, which more cement or less sand in the mortar would have prevented. Although he had seen several statements contesting his conclusion as to the effect of magnesia from sea-water on concrete, he had not yet heard any one dispute his statement as to the proper proportions of cement, sand, and gravel or stones in the composition of concrete (pp. 8 and 9 of his report). or contend that 1 of cement, 4 of sand, and 4 of gravel was a proper proportion to resist percolation, and that a work so constructed had successfully withstood the forced percolation of, and deterioration from seawater. Although his investigation at Aberdeen, with the consequent experiments, justified his conclusion, his opinion had been further strengthened by several other cases on which he had been consulted both before and after the Aberdeen report. In 1865, for the sake of economy, he took advantage of the increasing strength of Portland cement to make some hand-built rubble blocks for the Tyne north pier, with mortar gauged with 1 of Portland cement to 4 of sand, which were strong and looked well. But, on a rainy day, he observed that the rain-water, instead of running off as it did from the stronger mortar, filtered through them; and he never used 4 of sand to 1 of cement afterwards, either in concrete or mortar. In 1881–2

he was consulted about two graving docks in South Shields, inside which some of the concrete had deteriorated, which injury was cured by substituting concrete with a much larger proportion of cement. A large deep graving dock was constructed of concrete at Wallsend in 1885–7, which, before completion showed signs of deterioration from percolation. On his recommendation the porous concrete was replaced, where possible, by a stronger composition, and the pump culvert, which ran through one of the walls reducing its section, was filled up, a large cast-iron pipe being substituted at the back of the wall, which with other remedial measures had been partially successful. About the same time, he was consulted about signs of deterioration from percolation in a new graving dock at North Shields, the defects in which, by his advice, were in a great measure remedied by watertight cement plaster outside, puddling a portion of the back of a wall, and drilling holes through the foot of a wall to run off the water from behind and reduce the pressure, the openings having self-closing valves on the dock face of the wall. The owner of this dock constructed a second one alongside, shortly after the Aberdeen report was published, and by his (Mr. Messent's) advice, used no concrete with more than $1\frac{1}{2}$ sand to 1 of cement in the mortar. This dock was opened in 1889, and was perfectly dry; so that in the case of two graving docks belonging to the same owner, within a few yards of each other, constructed with cement from the same makers, and subject to the same pressure, the one, made of concrete of inappropriate proportions, showed leaks, percolation, and deterioration; whilst the other, made of concrete of proper proportions, was perfectly sound and dry. Other docks, with concrete of approved proportions, had since been built on the south side of the Tyne with similarly satisfactory results, and further justified him in adhering to the conclusion stated in his Aberdeen report. Such a conclusion should not cause any want of confidence in the future use of Portland cement for sea work, but rather should inspire confidence in its use, as showing that concrete made of good average cement might be safely used for such work, and enjoy immunity from deterioration by sea-water if properly proportioned, and the mortar not weakened by too much sand. In many cases, the proportions of concrete might be altered from those originally specified, without increasing the cost, where sand and gravel were of nearly the same value. Mr. Vernon-Harcourt read his (Mr. Messent's) report "some years ago," which would account for the unintentional misrepresentation that "according to that report, all piers made of Portland Mr. Messent.

Mr. Messent. cement concrete were liable to deteriorate." He did not think that any part of the report justified such a construction, but rather, applying the first paragraph of p. 19 and before, to Mr. Vernon-Harcourt's work at Babbacombe, it would indicate that if the concrete of which it was made was composed of materials in appropriate proportions, it would be safe from any deterioration from sea-water, even if exposed to forced percolation. Should it be composed of materials in inappropriate proportions, if it was a pier where the tide rose simultaneously on either side, it was also comparatively safe; and the only portion for which any anxiety need be felt was that between high-water neap-tide and high-water spring-tide levels. "But even this, as shown, is a very slow process." He had had a rather extraordinary experience with blue lias lime mortar at the Tyne north pier. The first length of the north pier,[1] of about 1,400 feet, was built between 1856 and 1862. The free-stone walls were built in cement up to 4 feet below high-water spring-tides on the sea side, and to 7 feet below high-water springs on the harbour side. Above these levels, the masonry of the walls was built in mortar composed of 1 part of Lyme Regis lime, 2 of sand, and 1 of smiths' ashes. The work set hard and appeared satisfactory, as did the greater part even now; but after a few years, the free-stone coping of the sea wall began to rise on its bed, which was 22 feet above high-water spring-tides. He tried pointing the joints with cement; but the mortar bed continued to expand, and, where the cement held, the continued expansion burst the stone under the coping. He afterwards had the coping lifted, and found the mortar bed quite soft, having been evidently affected by the sea-water filtering through the porous freestone coping. The coping was reset in strong cement mortar, and also some of the facing courses behind, and they had since remained intact; but later on, the mortar on which the paving of the promenade was bedded, the mortar bed of the promenade freestone coping, and two or three of the rubble courses under the promenade coping became similarly affected. Portions of these were reset in strong cement mortar, which had prevented further movement. Beyond the 1,400 feet, no lime was used in the pier; and granite copings were substituted for freestone on the promenade. The lower portion of the lime mortar work, washed daily by the sea, remained in a good state thirty years after construction; and the only mortar deteriorated was from 19 to 22 feet above high-water spring-tides, and consequently only wetted by the sea when northerly gales caused it to

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. plate 8.

wash over the parapet, for fifty to sixty days in the year on an average. This indicated that occasional saturation by sea-water had a much more injurious effect on mortar than frequent or constant immersion. Mr. Messent.

Mr. V. de Michele observed that all the Papers were full of valuable information, and bore directly upon the Aberdeen failure, which could be explained in two words, "free lime," or caustic lime uncombined with any other substance. Had this not been present in the cement, expansion would not have taken place, and there would have been no disintegration. A larger quantity of magnesia than was usually found in cement would not have caused any increase in bulk, had the lime been thoroughly combined. The anxiety to have the strongest cement encouraged efforts to make it with the largest possible proportion of lime, to obtain the desired strength. There was, however, an exact maximum quantity which would combine; any less reduced the strength, and any greater left a portion free, which, if not thoroughly slaked before setting, ultimately expanded. It was easy to slightly exceed the maximum; and this excess was dangerous, and could not always be removed by air-slaking. In bad lime mortar, the "core" or over-burnt lime slaked after the lime in the work, causing its disintegration. Similarly in bad cement, the excess of over-burnt lime did not slake during setting, but absorbing water slowly, expanded long after in the work. It was absolutely essential for sound concrete work to give the first place and most careful attention to tests for expansion. For the ordinary pat test, the samples should be made about $\frac{1}{8}$ inch thick on glass, and immersed in water directly after gauging. If, when taken out at the end of seven days, they showed no indications by cracks of expansion, he had found from long experience that the cement was safe. Subject to satisfactory pat tests, the greatest growing tensile strength should be obtained, as well as extreme fineness and a high specific gravity. He had used Portland cement concrete in air, under ground, and in water, for the past twenty years. About twelve years ago he constructed a concrete quay wall in a river, covered and exposed every tide; it had a 6-inch face of concrete, composed of 4 of river ballast to 1 of cement, brought up with the main wall; and it was now absolutely sound and hard. Concrete would never fail in sea-water if made with cement free from excess of lime. Mr. de Michele.

Mr. Malcolm Paterson wished to know Mr. Bamber's distinction between the test by specific gravity, and the test by the weight of a fixed bulk. The bursting action of cement too scantily watered Mr. Paterson.

Mr. Paterson. was of great importance, and was overlooked in practice. In wet ground, contractors and others often favoured the use of the dry materials of concrete, trusting to chance for their incorporation with underground water. Last summer he took up some fireclay pipe-drains, laid with yarn and cement in the joints, which were nearly all defective, the cement being shattered, and the sockets split, though not exposed to the least weight. The pipes were of good quality, laid by an expert jointer, and tested under his own supervision six years before. The cement had swelled, either from defect in manufacture, such as over-liming or under-burning, or from deficiency of water in mixing. Probably so powerful an effect was due to one or other of the former defects. The experiments with a deficiency of water were useful, but the record was not complete without experiments made with excess of water, an error still more common, though not so destructive. The weather, the condition of the stone, gravel, or sand, and the character of these ingredients, affected the proportion of water to be added; but no more should be used than absolutely necessary for the incorporation of the ingredients into a semi-fluid, viscous, springy mass. He had made comparative experiments for concrete with ground engine ashes, and with carefully screened and washed river sand, and also with washed alluvial sand free from coal ash, woody fibre, and organic matter. In hardness, specific gravity, and quickness of setting, the results proved the great superiority of the ashes to any sand to be found in the West Riding. Also, wherever engine ashes were readily procured, they were cheaper than washed sand. The greater tenacity of sandstone concrete than of granite concrete, observed by Mr. Smith (page 69), was due to the cement keying better with the rougher surface. The plastering of exposed surfaces must always be precarious; but recently he had used the method of self-facing. For nearly horizontal surfaces, straight-edges were fixed at the finished level, enclosing suitable spaces, and between these, two men worked another plank, $1\frac{1}{2}$ inch wide, edgewise, striking every square inch of the surface with parallel blows of slight impact. With a little practice this method secured an excellent skin, not so smooth, but quite as close and solid, and probably as watertight as plastering, while far more durable. For vertical surfaces, the concrete was chopped in with the edge of the shovel, close to and parallel with the frame, which secured the same result. Cement rendering, moreover, was very liable to be cracked or lifted by the frost in situations where solid concrete remained intact.

Mr. Pilkington. Mr. W. Pilkington regretted the attempt to disparage Portland

cement concrete, specially in contact with sea-water; whereas the cement was in no way to blame for the failures which had occurred. He had made five thousand tests of Portland cement, and having used 60,000 tons of concrete, considered Portland cement of good quality the best material for any marine work. All through the first section of the Quebec Harbour Works, Messrs. Moore and Wright used only Messrs. Gibb's hydraulic cement, guaranteed to bear 800 lbs. at seven days in an ordinary briquette, and which stood every required test as to specific gravity, weight per bushel, and fineness. This cement was often received towards the close of one season, and held over until the following spring, so as to enable the contractors to continue their work before fresh cement could reach them from England, without the slightest injury being sustained by the frost, which remained for months at 20° to 25° below zero. To obtain impervious concrete, all voids should be filled up before cement or water was added; and on putting in the proportion of cement, the materials should be worked together dry, and then as much water added as the voids would allow. After putting it into the mixer and giving six turns, the concrete should stand for five or six hours before placing it under water with skips, and the resulting work would neither disintegrate or swell. In 1849–51 he constructed the lighthouse at Cape Recéef, Algoa Bay, Portland cement being used for slow-setting concrete, and Roman cement when quick-setting was needful; and grey lime was used for inside work. The whole of that work was mixed with pure sea-water, and was to-day a standing witness against those who wished to throw their own faults on Portland cement. A beacon erected at the same time, in line with the Roman Rock, built of quartzite with a hearting of broken stone and concrete, became so hard and flinted over that it shone in the sun like glazed pottery. Cement to be properly tested required an even temperature of 60° to 70°, each sample being taken from an aerated quantity selected from each cask; and no ramming should be allowed, otherwise an 800-lb. normal briquette might be raised to 1,500 lbs., and even to 2,000 lbs. from the same batch. Good comparisons were often obtained by sand mixtures; but he had invariably found that, with good cement, the result was always in the exact ratio of the quantity of sand employed, and therefore the old standard tests might be safely relied upon. Mr. Pilkington.

Mr. W. H. Price remarked that his twenty years' experience of the Manora breakwater at Kurrachee confirmed Mr. Carey's statement, that "concrete made of sound and well-burnt cement, varying from $\frac{1}{4}$ to $\frac{1}{12}$ part by volume, and gauged with sea-water Mr. Price.

Mr. Price. has been used for many existing structures in the sea, without visible deterioration, for a long term of years." It could not, therefore, be classed—as regards results—with the concrete structures which Mr. Smith alarmingly characterised as liable to destruction "from the chemical action of sea-water, and the sudden compression of air within the interstices." The Manora breakwater, which he had previously described,[1] was built of Portland cement concrete blocks of 27 tons each, set in regular rows without mortar, and founded at a depth of 15 feet below low water. The blocks were made in moulds on shore, and were lifted, conveyed, and set at ages varying from seven months to one month. The ratio of the bulk of the cement, as it left England, to that of the finished block was mostly one-eleventh. Salt-water was used in the mixing. About 3,500 tons of cement were used, procured in England from three different makers. The cement varied in weight from 120 to 104 lbs. per bushel; and it was tested by the late Mr. W. Parkes before shipment. In about one-fifth the number of the earlier blocks, 50 per cent. more cement was used; but experience in the quality of the materials was held to warrant the reduction which results had justified, though it was probably carried as far as prudence admitted. The reduction having effected a considerable saving in cost, it was the more satisfactory to record that the concrete had thoroughly fulfilled its purpose, showing no disintegration, softening, or swelling, and had practically required no repair; for the expenditure under that head, averaging only ½ per cent. per annum on the first cost of the breakwater, had been mainly applied to raising the top with a layer of concrete to make up for settlement into, and with the rubble mound, and to the "feeding" of the mound, mainly at the outer end. The chief enemy to the concrete had been that formidable mollusk the "Pholas," which ate into the exposed surface below half-tide level; but as its penetration did not exceed 2 to 3 inches, and the mouth of its "burrow" was small, it had not seriously damaged the blocks. This mollusk also ate into the hardest limestone, though not into granite or basalt. As regarded the suitability of Portland cement concrete for works where sea-water was required to be kept out, such as a graving dock, his experience had been satisfactory, especially in the case of a small graving dock, constructed at Kurrachee about twelve years ago for repairing the dredging vessels, mainly composed of concrete somewhat richer in Portland cement than that of the breakwater, and which had

[1] Minutes of Proceedings Inst. C.E., vol. xliii. p. 1.

continued free from failure or undue leakage. He was of opinion that the failure of Portland cement concrete at Aberdeen was an exceptional case; and he thought that such would be the opinion of most users of Portland cement in sea works. Mr. Price.

Mr. J. WATT SANDEMAN stated that the successful employment of Portland cement for marine works could only be attained by properly proportioning the cement to the sand, and the cement and sand to the aggregates. Having constructed piers, harbours and docks, including six graving docks, entirely in concrete, he had found that good Portland cement would be obtained if it complied with the following tests, and that durable concrete for piers and docks would be ensured by the following proportions. Mr. Sandeman.

Cement.—90 per cent. of the cement to pass through a sieve of 5,800 meshes to the square inch. Briquettes made of 1 measure of cement to 3 of sand, to be tested at seven, fourteen, twenty-one, and twenty-eight days, each being kept dry for one day, and the remainder of the time in water. The briquettes at seven days shall bear not less than 90 lbs. tensile strain per square inch. The briquettes at fourteen and twenty-one days shall regularly increase in strength, and those at twenty-eight days shall bear not less than 40 per cent. more stress than those tested at seven days. Thin pats of the cement poured out upon glass shall show no signs of expanding, warping, or cracking, during twenty-eight days, twenty-seven of which they shall have been kept under water. *Concrete for Sea Piers.*—The proportions for facework concrete to be 1 part by measure of Portland cement, 1½ of sand, and 4 of either gravel or broken stone, not larger than would pass through a ½-inch sieve. The proportions for hearting concrete to be 1 of Portland cement, 2 of sand, and 5 of gravel and broken stone. The gravel and broken stone to be screened free from sand, and to be not larger than will pass through a 2½-inch ring, and to average from that size down to what would be retained by a ¼-inch sieve. *Concrete for Graving Docks.*—The proportions to be 1 of Portland cement, 1½ of sand, and 3 of gravel or broken stone; and in the concrete, large displacers to be deposited at distances of 12 inches apart. The size of the gravel or broken stone should vary from what would be gauged by ¼-inch mesh to what would be gauged by a 1-inch mesh. The concrete should be deposited from skips or barrows; and shooting it from a height should not be allowed, as it tends to separate the aggregates from the mortar.

In 1878 he measured the volume of the interstices of various aggregates,[1] from which he deduced the most economical proportions which should subsist between cement, sand, and aggregates; but while it then appeared that the limiting proportions of cement to sand for impermeable mortar should be 1 to $2\frac{1}{2}$, recent experience showed that 1 to $1\frac{1}{2}$ of sand was the correct limit.

Mr. WILLIAM SHIELD (of Peterhead) thought that too much prominence was given to the chemical action of sea-water upon Mr. Shield.

[1] Minutes of Proceedings Inst. C.E., vol. liv. p. 251.

Mr. Shield. cement, and that more attention should be paid to the presence of quicklime in the cement, which was mainly due to the admixture of under-burnt nodules with the properly burnt clinkers. If the cement did not heave, well-constructed work would remain impervious to the action of sea-water. Some years ago he made a number of concrete blocks of 1 of Portland cement, 2 of quartz sand, and 4 of broken quartz rock. These blocks set very hard, and were stacked in the blockyard upwards of a year before being put into the work, at which time they were in a perfectly sound condition. They were placed in a slope in front of a sea wall several feet above high water, and were therefore only intermittently wetted. After they had been in the work for several months, he detected a network of exceedingly fine hair cracks over their surfaces, which gradually opened; and, after a lapse of some months, the blocks heaved and became so weakened that they were knocked to pieces by the waves. The blocks being numbered and dated, were easily identified; and he found that every one that failed had been made from the same cargo of cement. The other blocks made in the same manner, but with different cement, and occupying similar positions in the bank, showed no sign whatever of disintegration. A portion of a concrete wall, constructed several years ago on the north side of Peterhead Bay, had disintegrated and fallen to pieces in the same way. This was several feet above high water, and therefore not subject to sea-water forcing its way into its pores under pressure. Many cements which had been carefully made, and from which under-burnt nodules had been rigidly excluded, might be quite safe to use when comparatively fresh; but the difficulty was to find a test by which to ascertain, for certain, which cements were reliable. Until such a test had been discovered, thorough aeration seemed to be the main safeguard against failure. In subjecting small blocks of cement to the boiling test, he had found that those made from slightly caked surface cement stood perfectly, while those made from cement taken from the heart of the heap cracked and heaved considerably. Test briquettes made from the same slightly caked cement, stood a tensile strain, at eight months, of 550 lbs. per square inch.

Mr. Stevenson. Mr. Charles A. Stevenson gave the following facts, relating to works erected by Messrs. Stevenson, in connection with the alleged deterioration of concrete by salt-water. The outer end of the pier at Anstruther, near Fifeness, in the Firth of Forth, was constructed of Portland cement concrete *in sitû* in 1871. There were no signs of disintegration in the concrete; and the 18-ton to 100-ton

Mr. Stevenson.

concrete blocks of 1 to 6, which were deposited "at random" on the sea side, were unchanged even on their arrises, except where rubbing had taken place. The pier of Lochindaral, which was constructed of bag work in 10 feet of water at low water in 1877, showed no sign of decay. These examples, in conjunction with five other concrete harbour works erected prior to 1882, proved that properly constructed concrete did not suffer in 10 to 20 years from the action of salt-water, where there was an unbalanced pressure; and the character of treacherous should not be assigned to concrete, when in reality failure was due to improper proportions or defective design. The damage at the Aberdeen south breakwater was due to defective design causing compression of air inside, though the 1 to 9 concrete was too weak. At Berwick dock, though subjected to an unbalanced pressure, the 1 to 9 concrète, since 1873, had exhibited no appearance of disintegration or chemical action. The following cement test had been employed in all the recent works above mentioned, and many others, with perfect success. Bars of cement, 1 inch square in section and 12 inches long, were broken across supports 6 inches apart; and the breaking weight should not be less than 75 lbs. hung on the centre.

Mr. Swainson.

Mr. J. H. Swainson stated that when the Calliope graving dock, Auckland, of the construction of which he had charge, was opened in February, 1888, he noticed a slight exudation of magnesium hydrate, which occurred in nearly every instance where new work had been joined to old, and where, through an imperfect junction having been made, the salt-water was enabled to percolate into the interior of the walls. These walls were formed of rubble concrete, and were not rendered in any way, the concrete being carefully worked with a shovel against the face of the boarding so as to form a skin. The walls and altars had not suffered from any deleterious effect of the sea-water on the concrete.

With reference to the production of Portland cement in the Australasian colonies, he had made six briquettes, in 1886, from a sample of cement made by Messrs. Wilson, of Mahurangi, north of Auckland, New Zealand, the average strength of which when nine days old was nearly 750 lbs. per square inch. One briquette remained unbroken with a strain of 1,800 lbs., the limit of the machine (Adie's) on the $2\frac{1}{4}$ square inches. This cement weighed $126\frac{1}{4}$ lbs. per bushel, and left a residue of 10 per cent. on a 2,500-mesh sieve.

Mr. Bamber.

Mr. H. K. Bamber in reply to the correspondence, observed that, if the coarser portions of the cement, which Mr. Stoney said were the most highly calcined, were inert, and refused to combine with

Mr. Bamber. water, it was probably because, instead of semifusion in kilns, the clinkers had been quite fused. When that occurred, nothing would make the cement unite with water, even if finely ground. He agreed with Mr. Stoney and Mr. Draper that, in a properly burned cement, made from well mixed ingredients, there was actually no free lime, but that all of it was in partial chemical combination with the silica and alumina. In reply to Mr. Reid, he again asserted and could prove that the lime in the cement did combine chemically with the external surface of each grain of quartz sand, forming silicate of lime, if the continued presence of a sufficient quantity of water was assured. If allowed to become dry, no further chemical combination between the lime and silica could take place. Mr. Kidd objected to his calling iron slag cement "so called," but four lines after, Mr. Kidd himself said, "There were important differences between slag and Portland cements, more especially in regard to their chemical composition," which therefore justified his (Mr. Bamber's) remark. Mr. Paterson wished to know his distinction between the test of specific gravity and the test weight of a certain bulk. The specific gravity gave the exact relative weights of the cement itself, without any air spaces; and the weight of a bulk gave the weight of cement and air spaces. For instance, a cubic foot of cement with a specific gravity of 3 – 1, if it could be put into the measure without any air spaces, would weigh about 194 lbs., whereas, in the ordinary course of measuring, it would barely weigh 100 lbs. In reply to Mr. Griffith, he thought briquettes made with sand of specified quality and fineness, and cements, were useful, because this was how cement was used, and it could not be rammed into moulds like neat cement. Cement was never used neat, but mixed with sand, and, therefore, these tests showed more how the cement was likely to set in concrete.

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24 November, 1891.

GEORGE BERKLEY, President,
in the Chair.

The discussion upon the Papers on Portland Cement and on Portland Cement Concrete occupied the evening.

1 December, 1891.

GEORGE BERKLEY, President, in the Chair.

It was announced that the following Associate Members had been transferred to the class of

Members.

Robert Anderson.
Joseph Davis.
Henry Ewart.
Arthur Edmund Breton Hill., B.A. Sc.
Robert Nathaniel Hodges.
Charles William Hodson.
William Hutchinson.
Charles Jones.
Daniel Macalister.
William Marriott.
John Charles Melliss.
Joseph Newey.
William Thomas Olive.
Charles Reginald Parkes.
James Richmond.
Charles Radcliffe Thursby.
Sam Tomlinson.
John Edward Waller.

Also that the following Candidates had been admitted as

Students.

Edward Vincent Acton.
Henry George Vergottini Adler.
Frederick Warner Allum.
Frederick William Ascroft.
Montague Atkinson.
Lionel Vaughan Bennett.
William Benson.
Arthur Mowbray Berkeley.
Alfred George Bessemer, Jun.
Manuel José John Bidwell.
Herbert Biggleston.
Ruding Spence Birt.
Charles Herbert Bishop.
John Charters Boyle.
Charles John Brown.
James Buchan.
Arthur Rodney Burch.
Alfred Burner, R.N.
Arthur Shaw Butterworth.
Harry Frederick Carew-Gibson.
Victor Gosselin Carey.
William Alexander Cheeke.
Charles Archbutt Cooke.
Gerald Arthur Cowle.
Edgar Wrigley Cozens-Hardy.
Martin De Ville.
Frank Rogers Durham.
William Cecil Easton, B.Sc.
Henry Entwisle.
Harold Edgar Featherstone.
Ernest Rudolph Foy.
Frank Garrett, Jun.
Richard Thomson Glascodine.
Arthur Myles Grantham.
Louis Greene.
Lionel Clifford Haugh.
James Hall.
William Francis Hassell.
The Hon. Henry Worsley Holmes à Court.
Alaric Hope.
Walter Hudson.
Vivian Barker Hunt.
John Kemp-Welch, Jun., A.K.C.
Cyril Reginald Sutton Kirkpatrick.
Frédéric Tudor Kleczkowski.
Frederick Herdman Longhurst.
Walter Leahy Mansergh.

Students—continued.

Ernest Sydney Martin.
Robert William Henry Joseph Massé.
Bernard Maurice Robert Nicholls.
Frederick Douglas Walker Ogilvie.
Charles Henry Olley.
Edward Nathaniel Pearce.
James Pollock, Jun.
William Vyvyan Molesworth Popham.
John James Pulleine.
Alfred Henry Roberts.
Edward Richard Ernest Rotter.
George Norman Scarfe.
Paul le Juge de Segrais.
William Barbourne Shaw.
Frederic Shelford.
Robert Lewis Soper.
Frederick Owen Stanford, A.K.C.
Bryan Stapleton.
William Blackwell Statham.
Frank Torrens Stokes.
Arthur Marinus Alexander Struben.
Frederic Stuart.
Charlie Harker Sunderland.
George William Tyndale Tyndale-Biscoe, A.K.C.
Herbert Williams Umney.
John Leonard Vaizey.
Arthur Evan Vigers.
Maurice Villiers-Stuart.
William Garneys Wales.
Horace Reginald Walton.
Frank Leslie Watson.
John William Watson.
Leonard Kingsley Watson.
Arthur George Way.
William Smart Welton.
George Henry Whittaker.
Roland Cecil Wild.
George Bransby Williams.
Percival Robert Augustus Willoughby.
Arthur Charles James Wilmshurst.
Hervey Alan Wood.
William Richard Wood.

The following Candidates were balloted for and duly elected as

Members.

Henry Bawn Addis.
Alfred Brereton.
Louis Holt Butcher.
Eardley Bailey Denton, B.A., G.C.L. (Oxon).
William Gee.
James George Green.
Peter Seton Hay, M.A.
Henry Alfred Ivatt.
Lionel Montague Jacob.
Horace Chaloner Knox.
Douglas Austhwaite Stanley.
Major-General Charles Edmund Webber, C.B., late R.E.
Walter Henry Wilson.
John Young.

Associate Members.

George Herbert Abbott.
James Hartley Abbott.
Robert Adam, Stud. Inst. C.E.
George Thomas Cooke Adams, Stud. Inst. C.E.
Luis Andreoni.
Charles Anthony, Jun., Stud. Inst. C.E.
Thomas William Arnall.
Arthur James Arnot, Stud. Inst. C.E.
Thomas Lambert Ayres.
Léon Harry Barker.
Ernest James Barrett.
Johan Ernst Berg.
William Walton Berry.
John Blackbourn.
Reginald Pelham Bolton.
Arthur Bowes.
Leonard Brereton.
Charles Briggs.
Albert Brooks, Stud. Inst. C.E.
Hillersden Bulteel, Stud. Inst. C.E.

Associate Members—continued.

George Thomas Burdett, Stud. Inst. C.E.
Alfred Ernest Caldicott, Stud. Inst. C.E.
William Lochiel Sapte Lovett Cameron.
Arthur Cleghorn Lyons Campbell.
Henry Couper Castilla.
Alfred Clough.
George Shorey Coakes, B.A.
Henry Francis Collins, A.R.S.M.
Daniel Connery, M.E.
Alfred Ernest Cooper.
William Robson Crabtree.
Alfred McCallum Cross.
Otway Fortescue Luke Wheeler Cuffe, Stud. Inst. C.E.
John Davy, A.K.C., Stud. Inst. C.E.
Ruttonji Dhunjibhoy (*Khân Sahib*).
Edward Carus Driffield.
Herbert Evington, Stud. Inst. C.E.
Robert Nesham Farquharson.
Giulio Festa, Stud. Inst. C.E.
Robert Alexander Fletcher, Stud. Inst. C.E.
John Cunningham Ford.
Henry Llewellyn Thomas Foster, Stud. Inst. C.E.
George Garson, B.Sc.
Lawrence Gibbs, Stud. Inst. C.E.
Robert Gilmour.
Thomas Glover, Jun., Stud. Inst. C.E.
John Gow.
John Graham.
William Henry Grahame.
George William Green, Stud. Inst. C.E.
Robert Harry Morris Green, Stud. Inst. C.E.
Allan Greenwell.
Thomas Alexander Guyatt, Stud. Inst. C.E.
Robert Stuart Hanckel, Stud. Inst.
William Scott Herriot.
Ernest Prescot Hill.
Charles James Hobbs, Stud. Inst. C.E.
James Holden.
Edwin Collett Homersham.
Edward Hooper.
John Hopwood.
William John Howley, Stud. Inst. C.E.
Henry Albert Hoy.
George Frederick Jackson, Stud. Inst. C.E.
Evan Davies Jones.
Harry Herbert Jones, Stud. Inst. C.E.
Henry Cecil Jones.
Montague Rhys Jones.
William Jopp.
Bertrand Thornton Knight.
William Lachlan.
Bradford Leslie.
Alfred James Linnell, Stud. Inst. C.E.
James Struthers Louttit.
George Andrew Middlemiss Luff.
Arthur Lund.
George Trotter Lynam, Stud. Inst. C.E.
William MacGlashan, B.Sc., Stud. Inst. C.E.
James Mair, Wh.Sc., Stud. Inst. C.E.
James Waddell Malcolmson, Wh.Sc., Stud. Inst. C.E.
Arthur Woodroffe Manton, Stud. Inst. C.E.
William Frederick de Mole.
Robert Bridges Molesworth, M.A.
Kentish Moore, Stud. Inst. C.E.
Robert Bradshaw Moorhead, B.A.
Henry Vereker Lloyd Morony, B.E.
James Robert Mudie.
Frederic Walter Newson.
Thomas Benson Nowell.
Arthur Matthews Paddon, Stud. Inst. C.E.
Herbert Phillips.
Joseph Spiers Pickering, Stud. Inst. C.E.
Alfred Lee Pogson.
Robert Barnabas Pollitt.
Dorabjee Bhikhajee Rabadina.
William Sancroft Randall.
Sydney Raymond, Stud. Inst. C.E.
Frank Rayner, Stud. Inst. C.E.
Henry Ashman Reed, Stud. Inst. C.E.
Herbert Peter Barrow Rigby, Stud. Inst. C.E.

Associate Members—continued.

OLIVER HERBERT ROGERS.
CHARLES THORNTON RENNIE SCOVELL.
HARRY SHOOSMITH, Wh.Sc., Stud. Inst. C.E.
CHARLES FREDERICK SILLEM, B.A., Stud. Inst. C.E.
ALEXANDER SINCLAIR.
JOHN GERVAIS SKIPTON.
GEORGE MAYNARD STAINFORTH, Stud. Inst. C.E.
RICHARD STANFIELD, Wh.Sc., F.R.S.E.
ALEXANDER STEWART, Stud. Inst. C.E.
THOMAS STEWART, Stud. Inst. C.E.
WILLIAM ARCHER PORTER TAIT, B.Sc., Stud. Inst. C.E.
HERBERT WILLIAM TATE.
JOHN ARTHUR THORNTON, Stud. Inst. C.E.
ALBERT TILLEY.
GEORGE ADOLPHUS TIMME.
ALFRED DRYDEN TUDHOPE.
GEORGE VIBART.
MURRAY WALKER, Stud. Inst. C.E.
ROBERT WALKER, Jun., B.E., Stud. Inst. C.E.
FREDERICK DARWENT WARD, Stud. Inst. C.E.
JAMES CARPENTER WARD.
THOMAS WILLIAM CHAPMAN WARD, B.E.
WILFRID JOHN ARIS WATKINS, Stud. Inst. C.E.
WILLIAM STEPHEN WATSON, A.N.S.S., Stud. Inst. C.E.
SIDNEY HERBERT WELLS, Wh.Sc., Stud. Inst. C.E.
JAMES WHITAKER, Wh.Sc., Stud. Inst. C.E.
GUILLERMO ANDRES WILSON.
JOHN HAROLD WOODWARD, Stud. Inst. C.E.
THOMAS TRAFFORD WYNNE.
FRANCIS COLIN YORK.

Associates.

JOHN BLOYD DONKIN.
DMITRI THEODOR JARENTZEFF (Colonel I.R.N.)
ROBERT ROBERTS.
JOHN PRATT YOUNG.

The discussion upon the Papers on Portland Cement on and Portland Cement Concrete was continued and concluded.

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